Where is your Guardian Angel?
Locating and Protecting Vulnerable Road Users

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Institute of Communications and Navigation

ICL-GNSS 2018
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30
ZONE

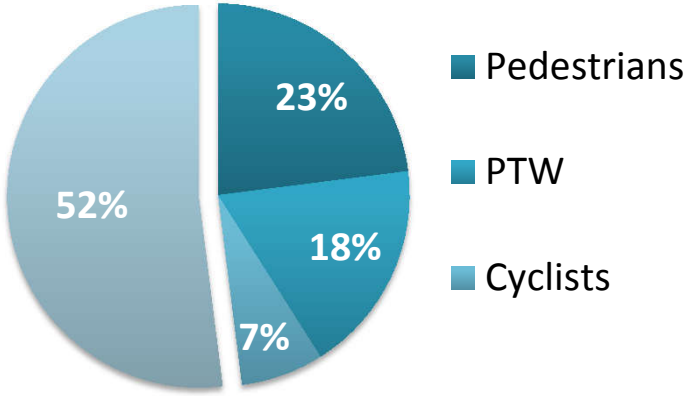
VRU Accident Statistics

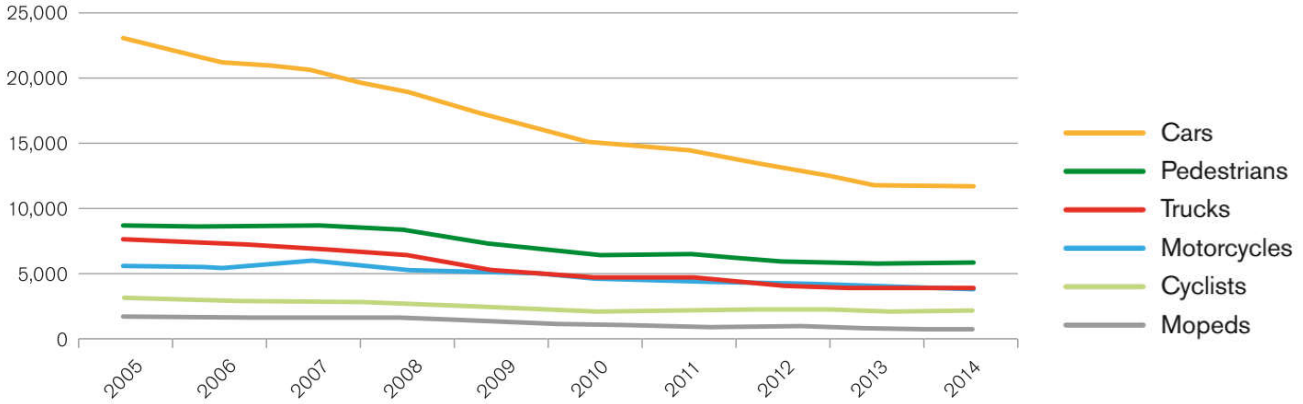
motojektif.com

Vulnerable Road Users

- On European roads:
  - Around 28.000 fatalities and 250.000 serious injuries every year
  - VRUs comprise 46% of all fatalities

Traffic accidents in Europe



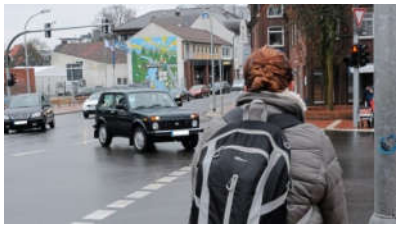


Source: European Commission, (2016). Annual Accident Report, European Commission, Directorate General for Transport, June 2016

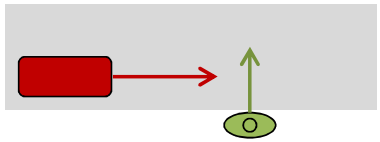
Relevant Scenarios

Pedestrian

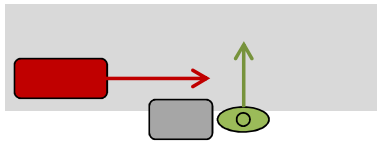
Schwäbisches Tagblatt - Franke



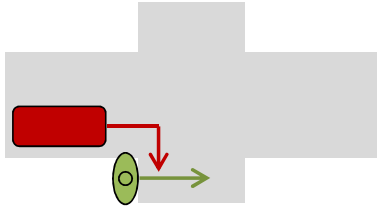
Tim Henrichs



49.4 %

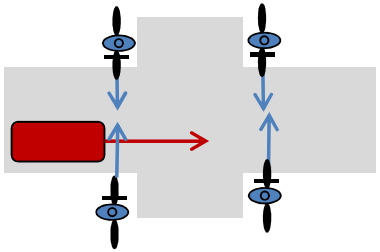


29.7 %

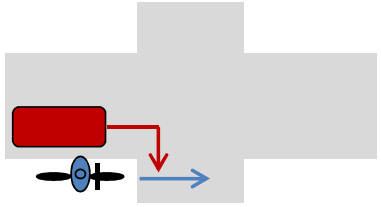


7.6 %

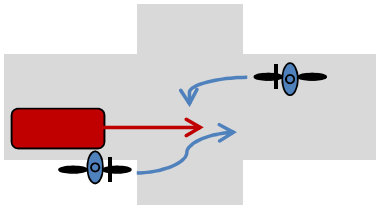
Cyclist



65.1 %



16.5 %



9.1 %

NWZ Online

Source: GIDAS - German In-Depth Accident Study 2013

Main Reasons for Accidents

- Distraction (smartphone, radio, etc.)
- Physiological (fatigue, effect of alcohol, etc.)
- Situational misinterpretation
- Circumstantial
  - Road conditions (wet, icy, etc.)
  - Meteorological conditions (rain, fog, low-sunlight, etc.)

http://driving.ca

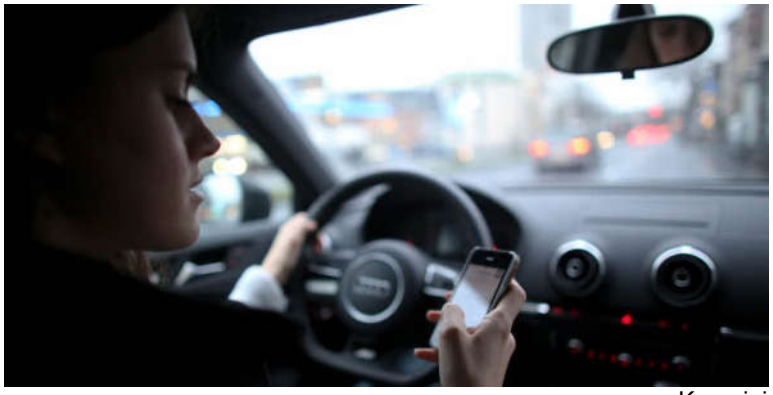
VRU Protection - Passive

- Helmets for cyclists and motorbikers
- External pedestrian protection Airbags
- Lifting bonnet
- Infrastructure

VRU Protection - Active

- Driver Assistance Systems
  - Automatic Emergency Brake
  - Adaptive Headlights
  - Driver State monitoring

Ford



Krasniqi

Volvo

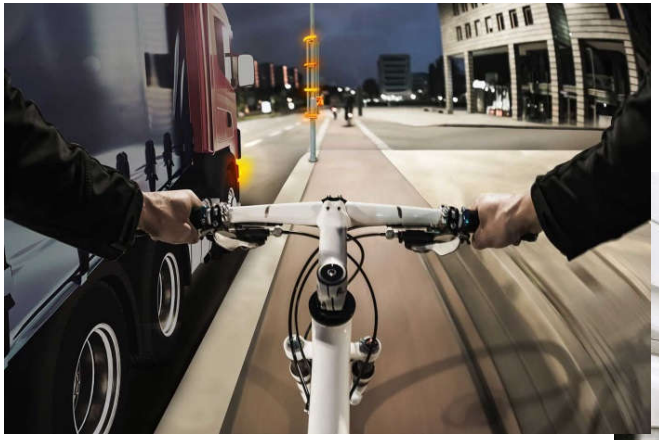
Volvo

VRU Protection - Active

- Daimler Blind-Spot Assist for trucks: eligible equipment for 2.500 Euro!
- European Commission proposes the use of a right turning assist warning device (without AEB)

Daimler AG

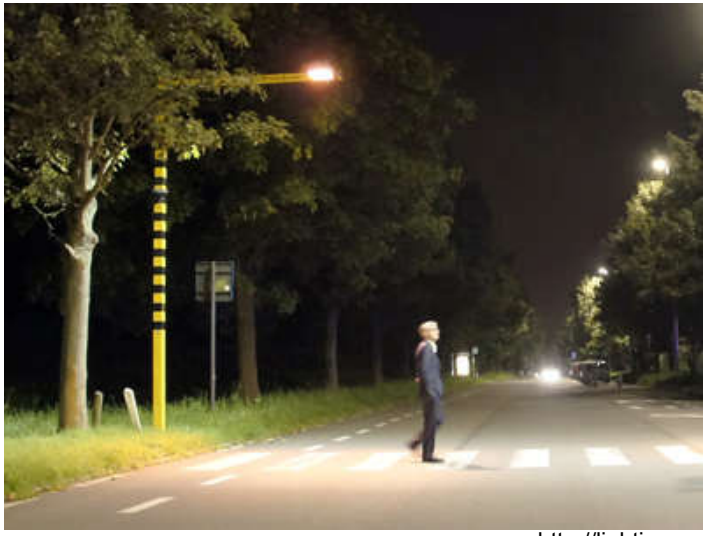

Daimler AG


https://bike-flash.de/


https://bike-flash.de/

VRU Protection – Infrastructure deployment

SenUVK, Bloomimages



http://lighting.eu

Engineering &Technology

Collision Detection/Avoidance Algorithms

Warning | **Motion Control**

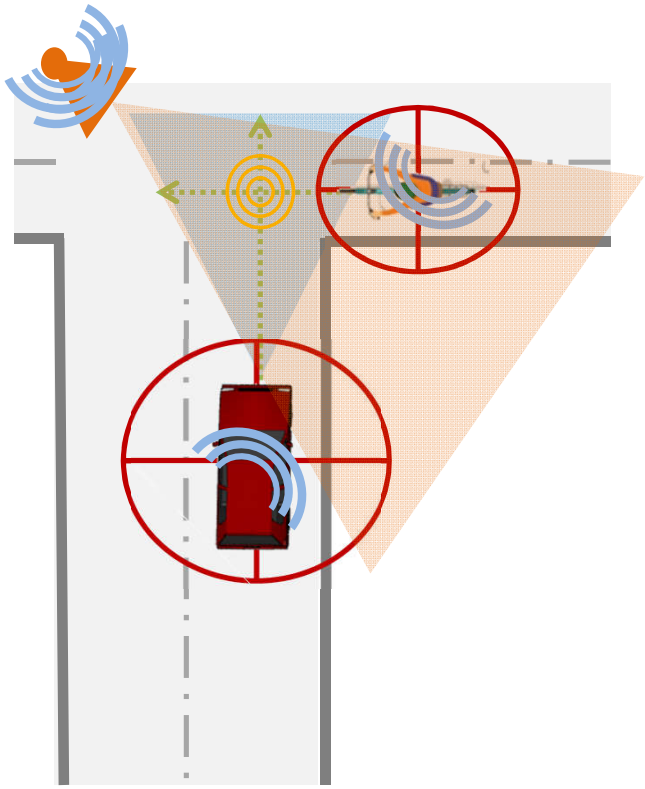
Collision Detection

Trajectory prediction

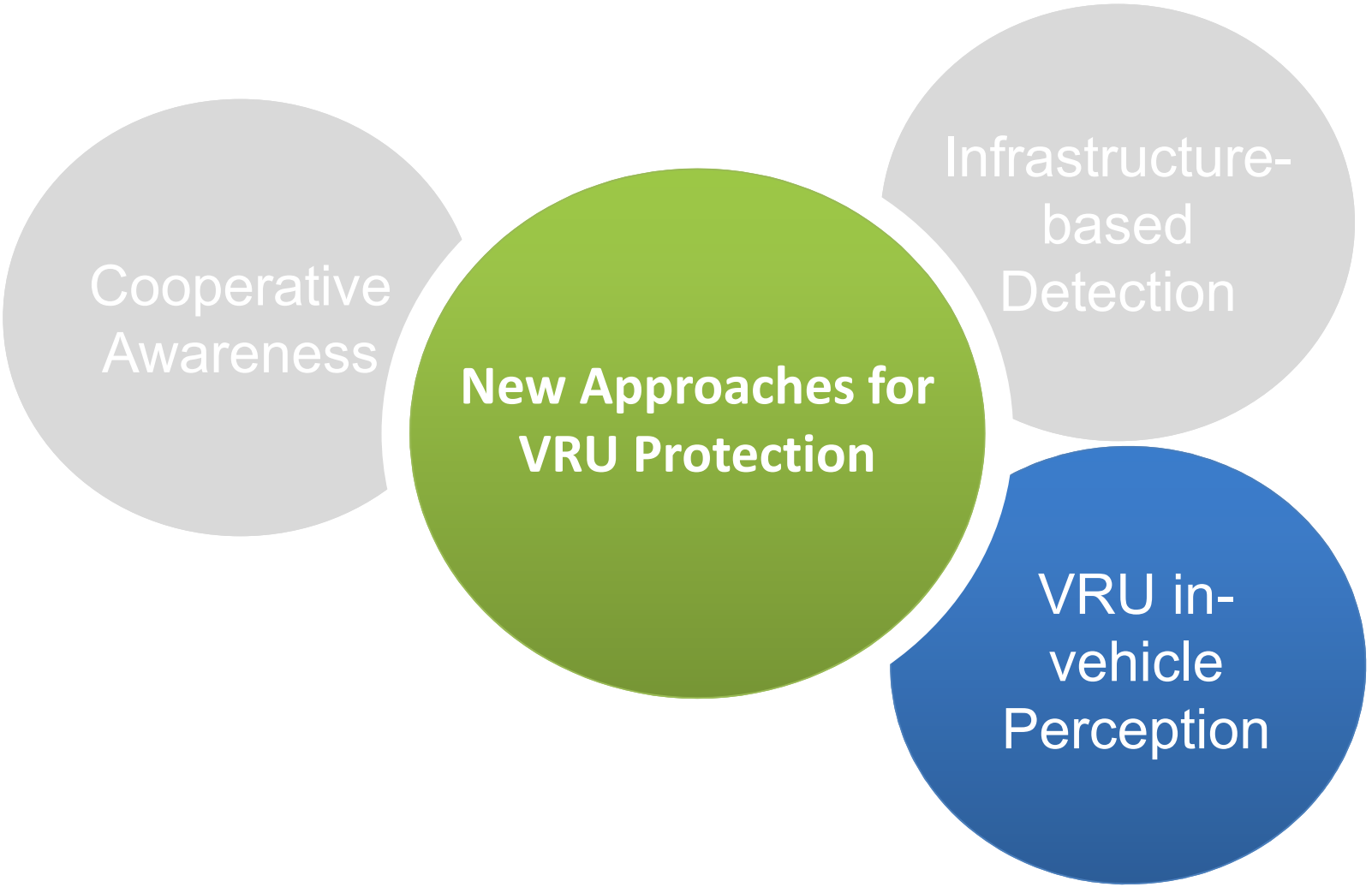
Map

Perception | **Communication**

Localization | **Infrastructure**

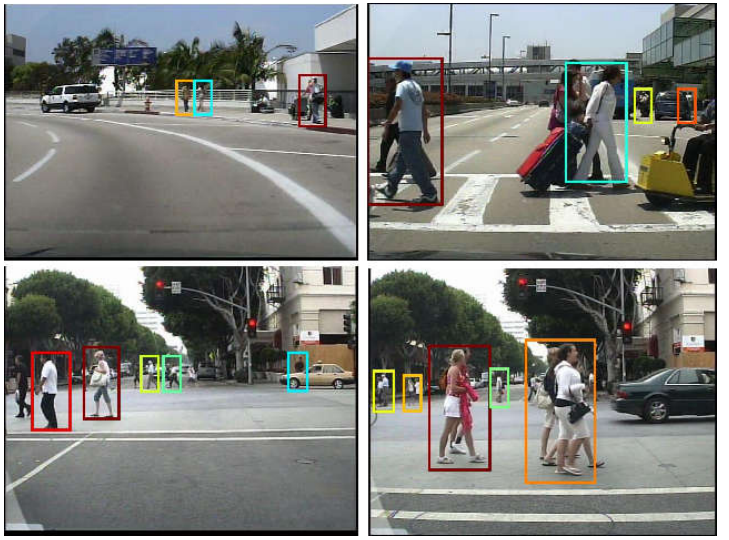


- Increase awareness:
  - → Robustness
  - → Reliability
  - → Minimize false detections and mis-detections
  - → Minimize the number of warnings

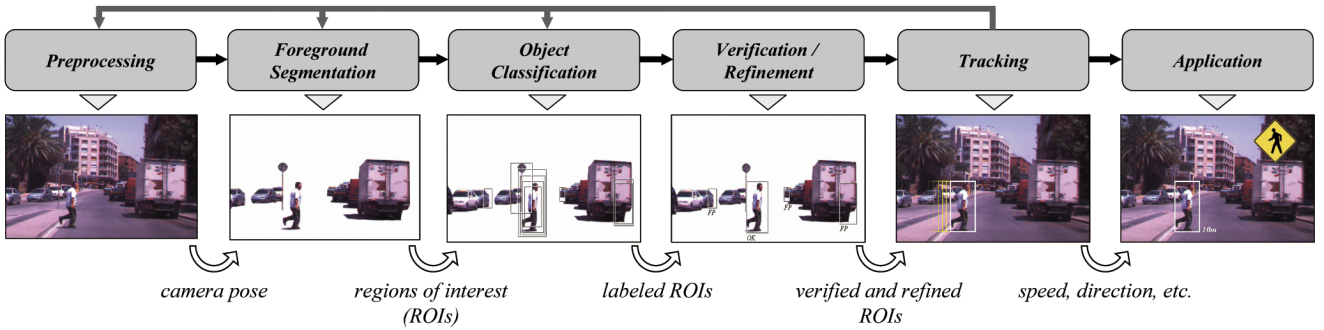

Cooperative Awareness
New Approaches for VRU Protection
Infrastructure-based Detection
VRU in-vehicle Perception

VRU in-vehicle Perception

- Mono/Stereo Camera and/or night-vision
- Process:
  - Detection via image processing: Segmentations
  - Classification via Machine Learning Techniques (Support Vector Machines and Neural Networks)
  - Tracking
- Detection rate of 90% on simple datasets
- Challenges remain:
  - Bad lighting and meteorological conditions
  - Partly or complete occlusion



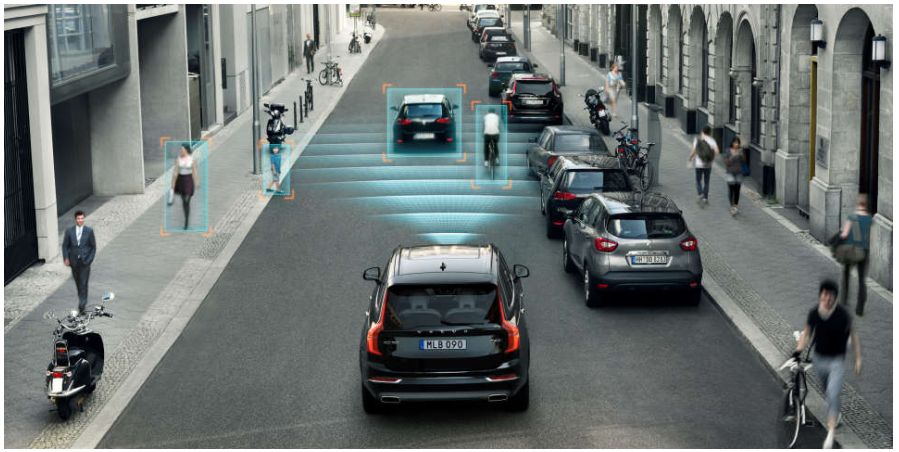
Source: Cho, H., Rybski, P.E., Bar-Hillel, A., & Zhang, W. (2012). Real-time pedestrian detection with deformable part models. 2012 IEEE Intelligent Vehicles Symposium, 1035-1042.



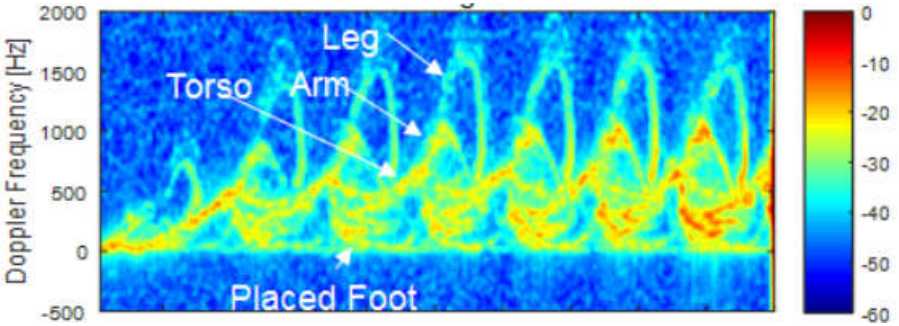
Source: A. D. Sappa, A. M. López, T. Graf and D. Gerónimo, "Survey of Pedestrian Detection for Advanced Driver Assistance Systems," in *IEEE Transactions on Pattern Analysis & Machine Intelligence*, vol. 32, no. , pp. 1239-1258, 2009.

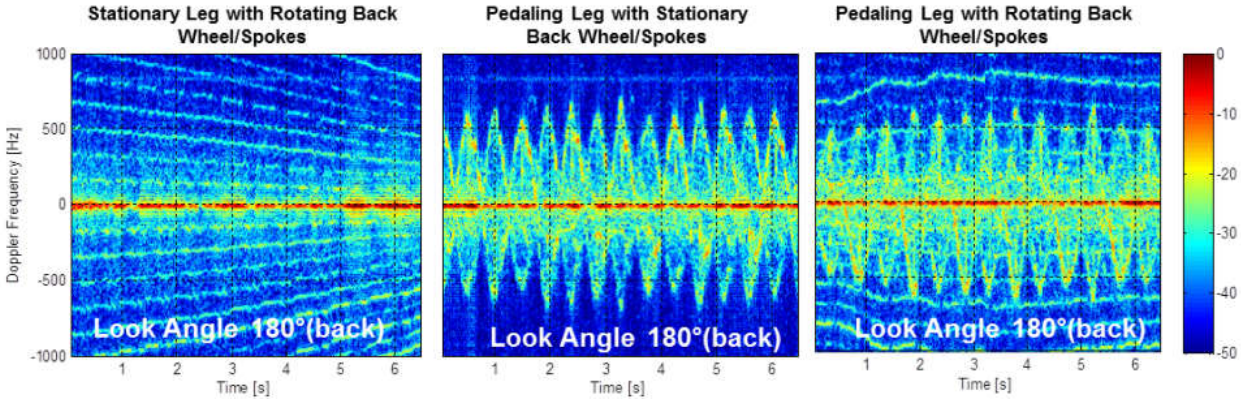
VRU in-vehicle Perception

- Automotive Radar at 76 GHz
- Challenge:
  - lower reflectivity
  - smaller radar cross-section
  - Point targets
- Distinguish between pedestrians and small static objects
- Use of micro-Doppler for classification



Volvo



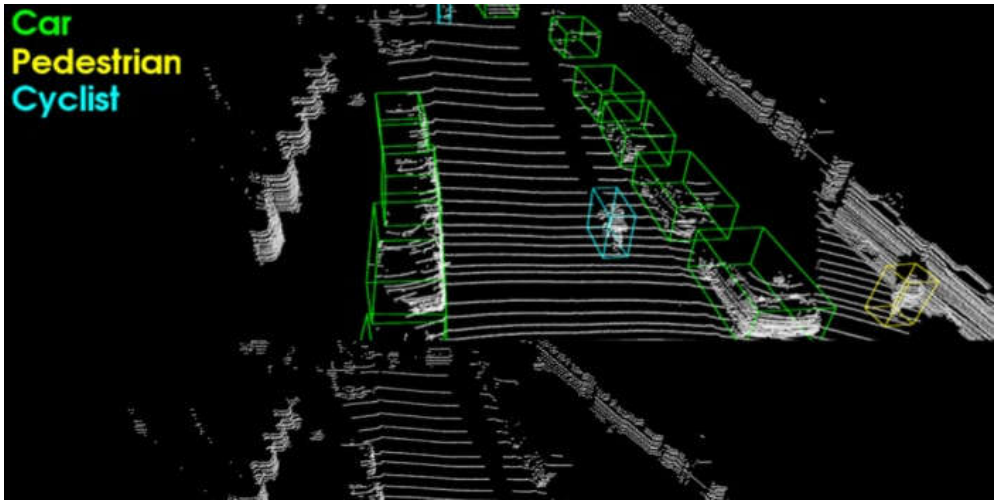


D. Belgiovane and C. Chen, "Micro-Doppler characteristics of pedestrians and bicycles for automotive radar sensors at 77 GHz," *2017 11th European Conference on Antennas and Propagation (EUCAP)*, Paris, 2017, pp. 2912-2916

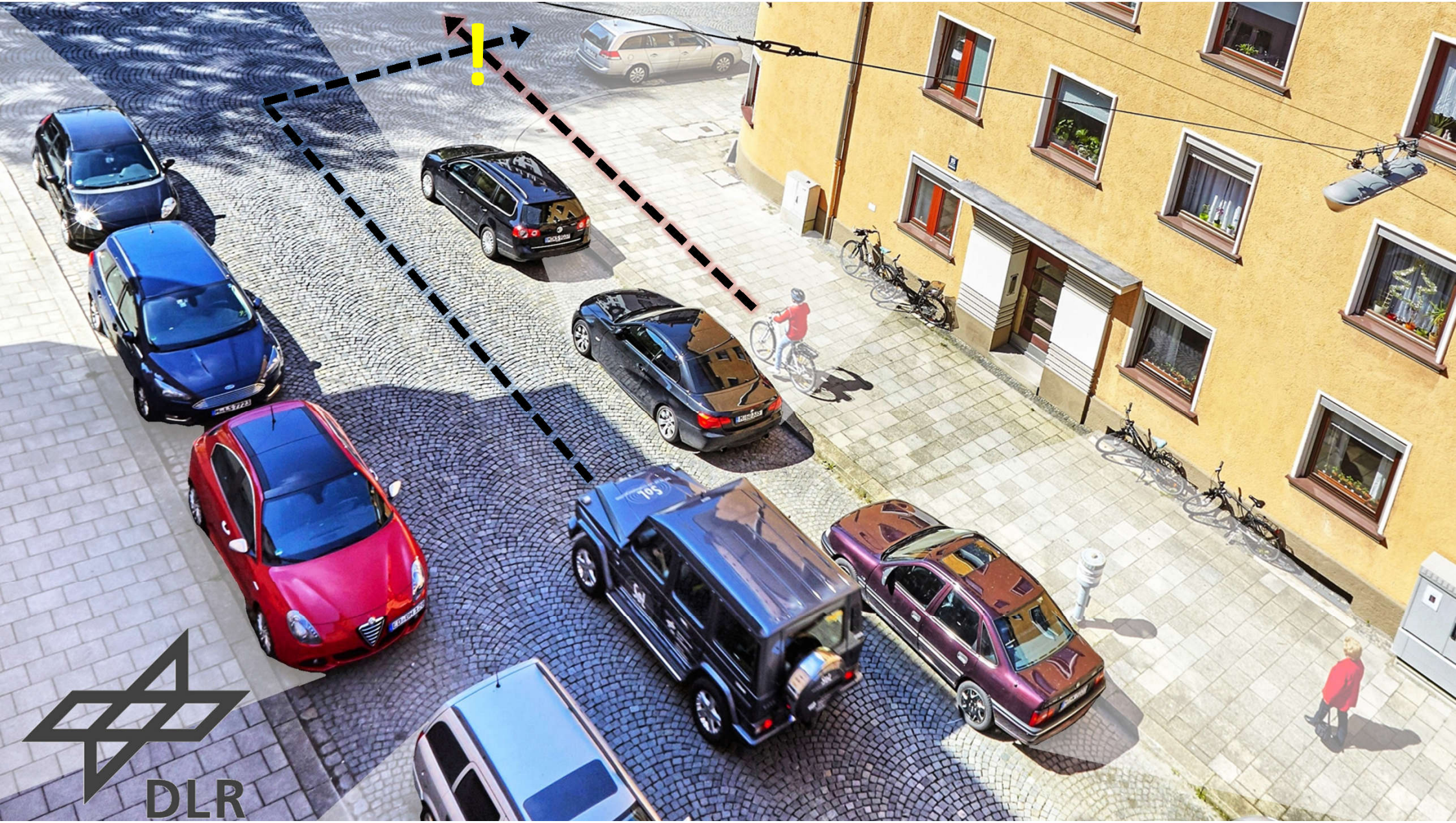
VRU in-vehicle Perception

- Laser scanners and Lidar
- Advantage: range accuracy
- Disadvantage: climatologic conditions, resolution and price

Fernando García, Felipe Jiménez, et al., ”Distributed Pedestrian Detection Alerts Based on Data Fusion with Accurate Localization”, Sensors 2013, 13(9), 11687-11708

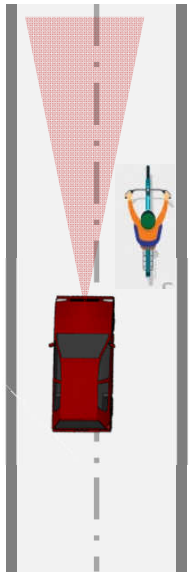


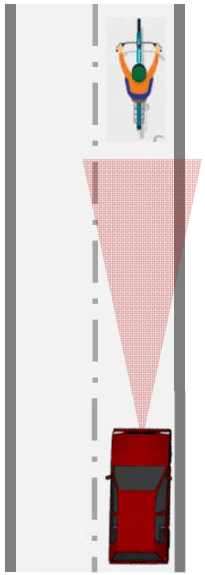
Ibeo LUX / AutonomousStuff

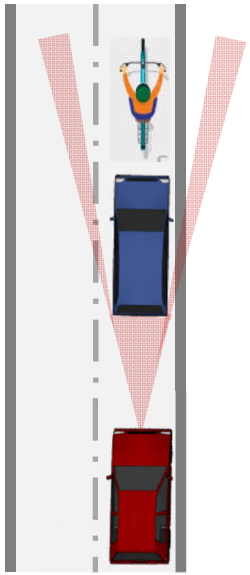

!
DLR

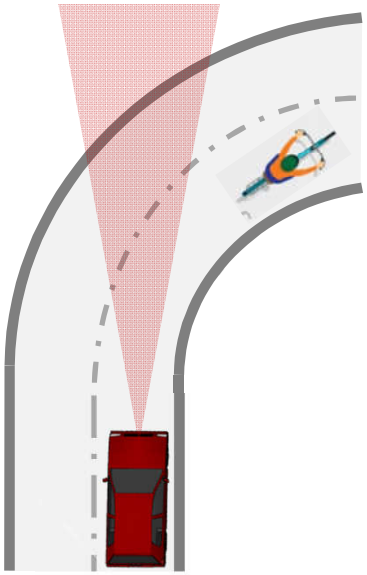
VRU Detection via On-board sensors

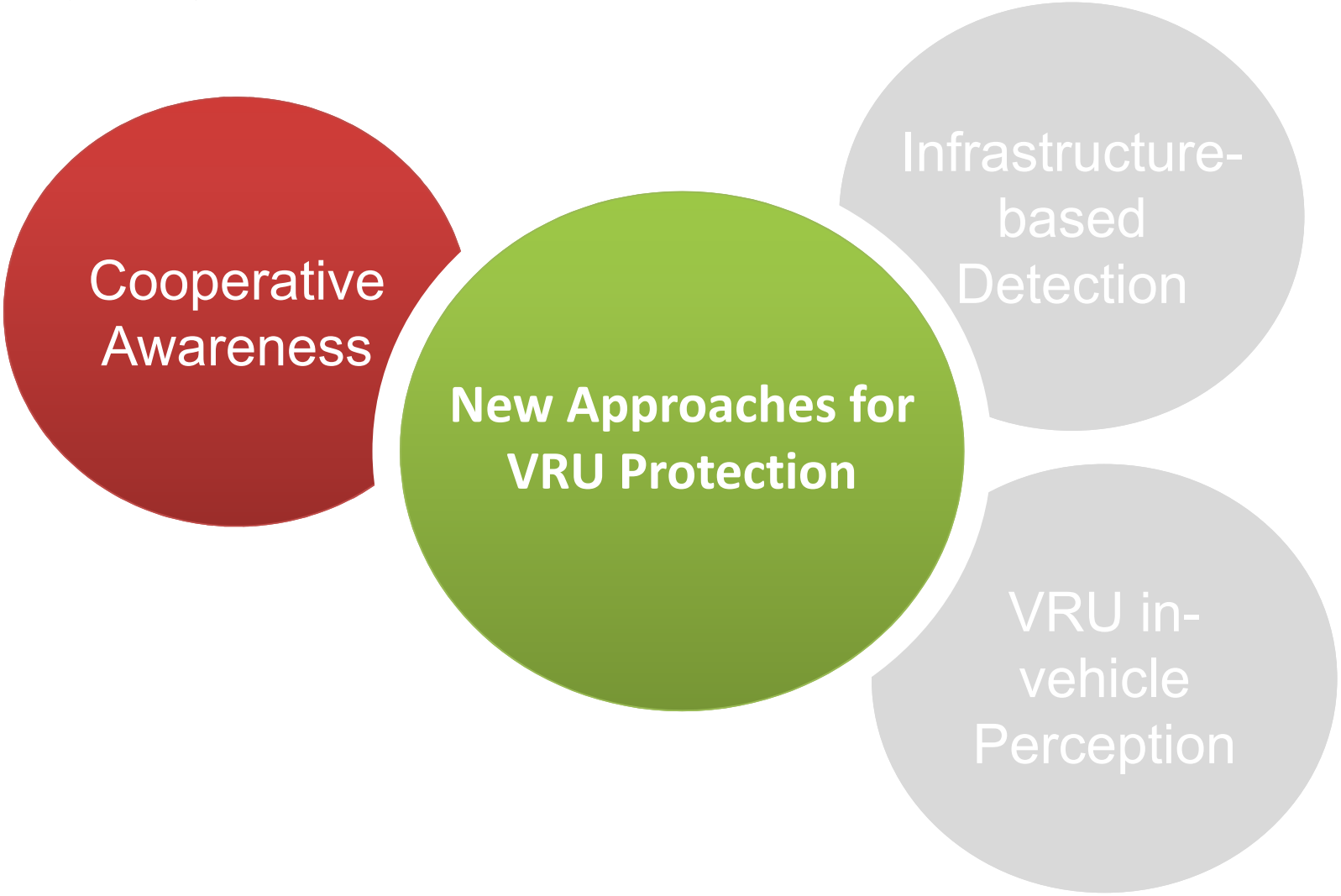
- Limitations of on-board sensor detection:
  - Directive
  - Limited range
  - Blockage - line-of-sight – No obstructions
  - Limited availability: luminosity and climatological conditions










Cooperative Awareness
New Approaches for VRU Protection
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Smartphones

- Increased computational power
- Build-in sensors:
  - GNSS
  - Inertial and magnetic
  - Sound and light
- Built-in communication:
  - Cellular communication: LTE, 5G
  - Wireless communication: WiFi and V2X (ITS-G5 / DSRC)
  - Short-range: BLE
- Build-in HMI: visual, haptic and acoustic

V2X Communication

- Ad-hoc communication via ITS-G5 / DSRC
  - IEEE 802.11p PHY and MAC
  - Effective range of 300m
  - Omnidirectional awareness
- But….what about equipping VRUs?

  “Recently Qualcomm addressed this concern by announcing their capability to override and upgrade existing Wi-Fi firmware to operate in DSRC band without any additional hardware cost.”

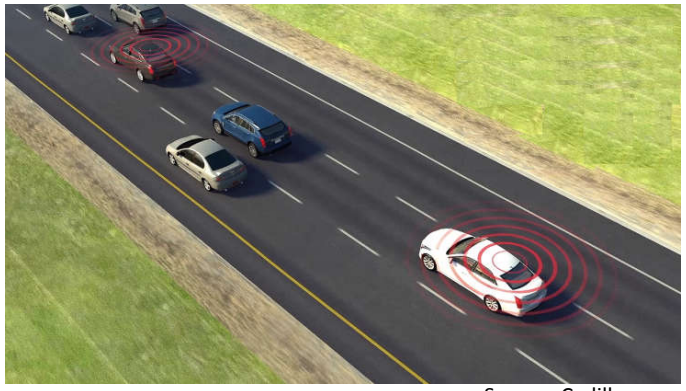
Source: A. Tahmasbi-Sarvestani, H. Kazemi, Y.P. Fallah, M. Naserian et al., "System architecture for cooperative vehicle-pedestrian safety applications using DSRC communication", SAE Tech. Paper 2015-01-0290, 2015.

Cohda Wireless

Kapsch

V2X Communication

- Communication impairments:
  - Physical - Layer
    - Low signal level (attenuation, shadowing / LoS-blockage or Interference)
    - Non-ideal channel propagation (multipath, fading, Doppler, etc.)
  - Medium Access – Layer
    - Packet collisions (e.g. due to hidden terminal)



Source: Cadillac.com

Source: Berliner Zeitung

Vehicle-to-Pedestrian Communication

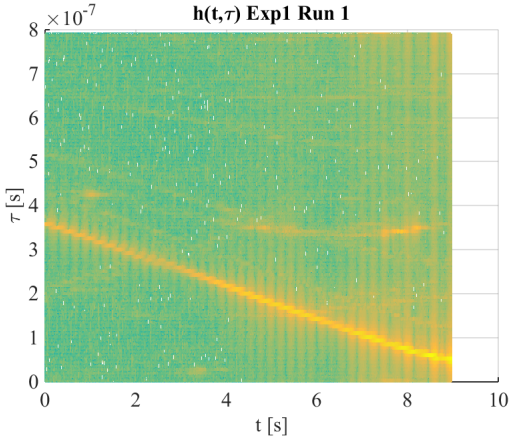
- Reliable vehicle-to-pedestrian communication (V2P):
  - Knowledge about propagation conditions
  - Accurate V2P channel model for critical situations
    - For communication system design
    - For evaluation in test environments

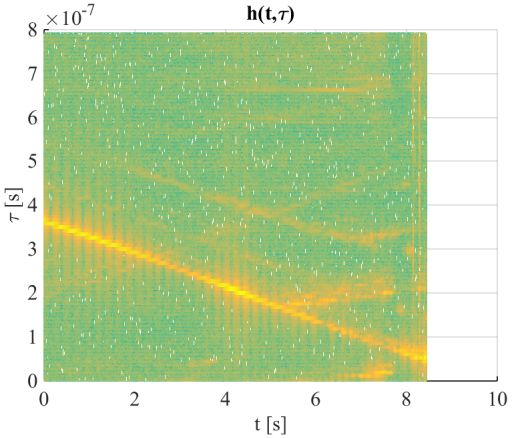
RX

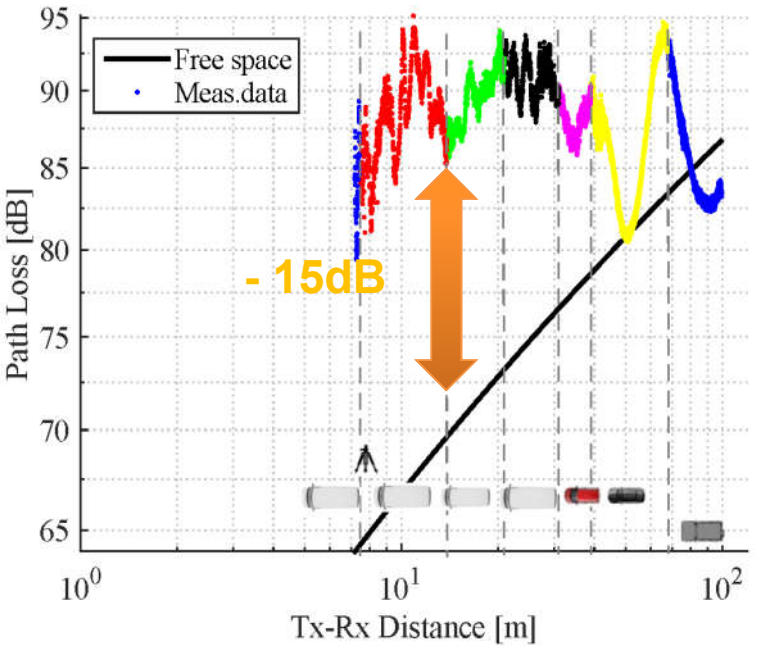
TX


DLR
Hertz
Hertz

Vehicle-to-Pedestrian Communication



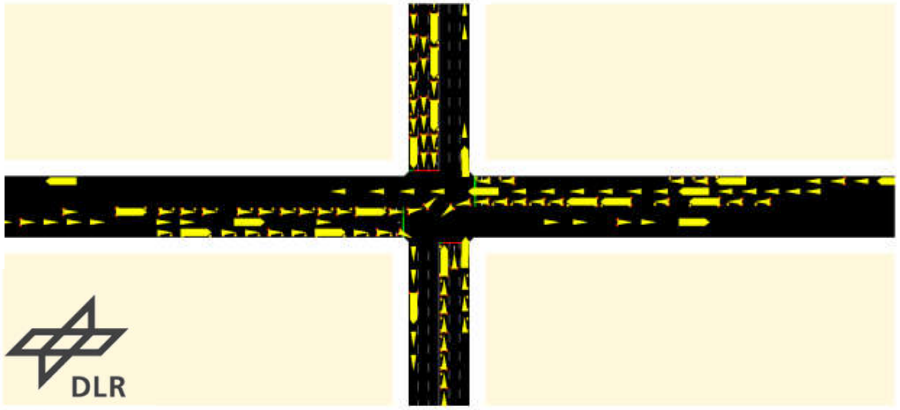




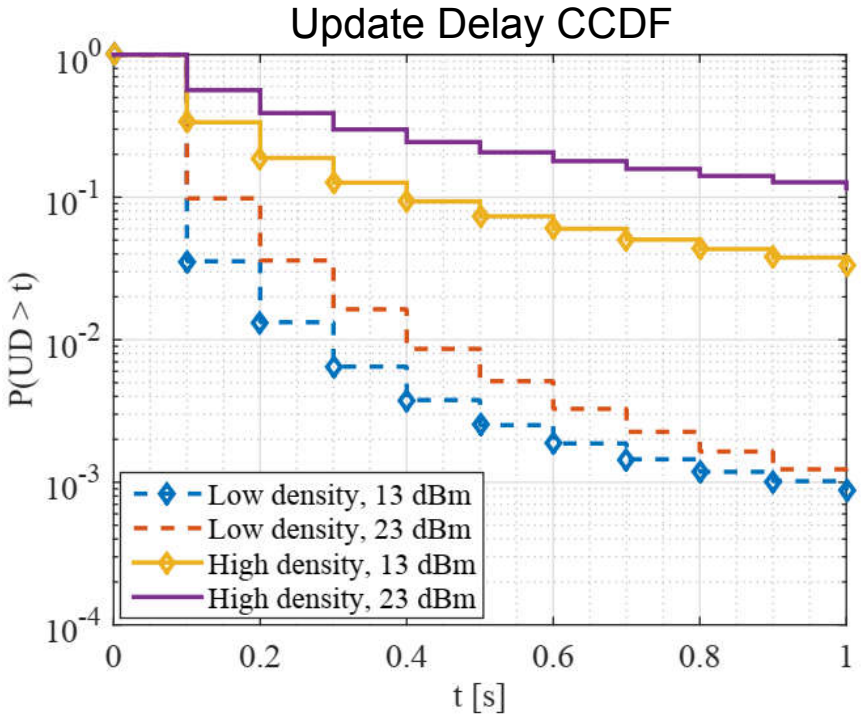
Source: Rashdan, Ibrahim und Ponte Müller, Fabian und Wang, Wei und Schmidhammer, Martin und Sand, Stephan (2018) *Vehicle-to-Pedestrian Channel Characterization: Wideband Measurement Campaign and First Results.* EuCAP 2018, 9.-13. Apr. 1018, London, UK.

V2X Communication

- Dense traffic scenarios at urban intersections



Simulation Environment: Sumo and Omnet++

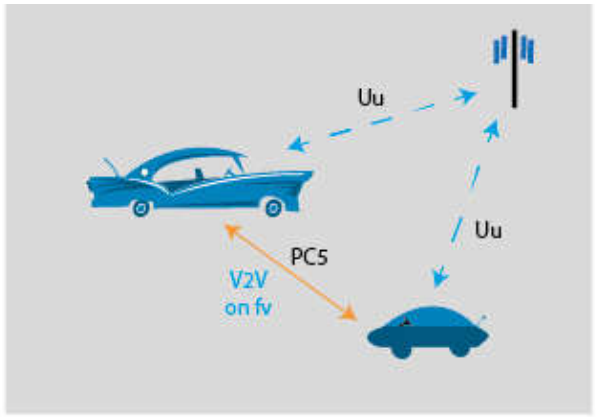


- Higher modulation rates → Shorter Packets → Less Congestion
- Current standardization activities in IEEE: Next Generation Vehicle Study Group

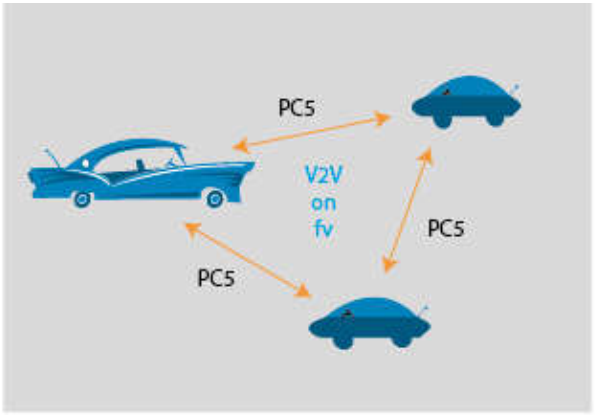
Source: Rashdan, Ibrahim und Schmidhammer, Martin und Ponte Müller, Fabian und Sand, Stephan (2017) Performance Evaluation of Vehicle-to-Vehicle Communication for Cooperative Collision Avoidance at Urban Intersections. 2017 IEEE 86th Vehicular Technology Conference: VTC2017-Fall, 24-27 Sep 2017, Toronto, Canada.

LTE-V2X (a.k.a cellular V2X)

- September 2016: Release 14 enables LTE-V2X over sidelink (PC5)



Mode 3



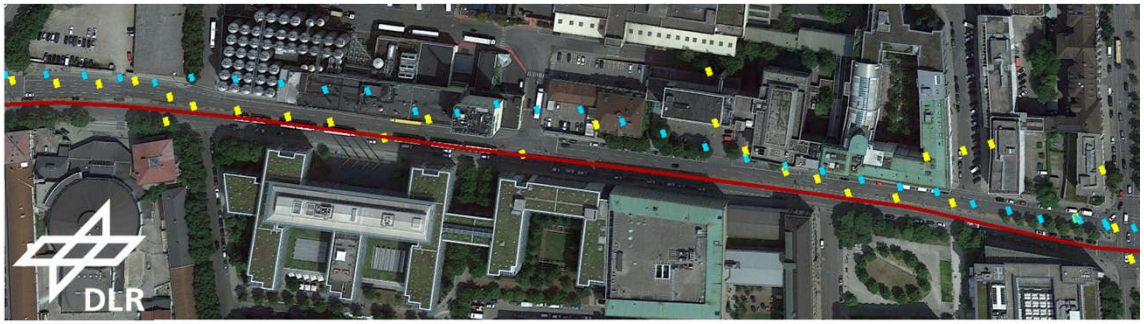
Mode 4

- Release 15 in Q3 2018 is already including the first 5G standards.

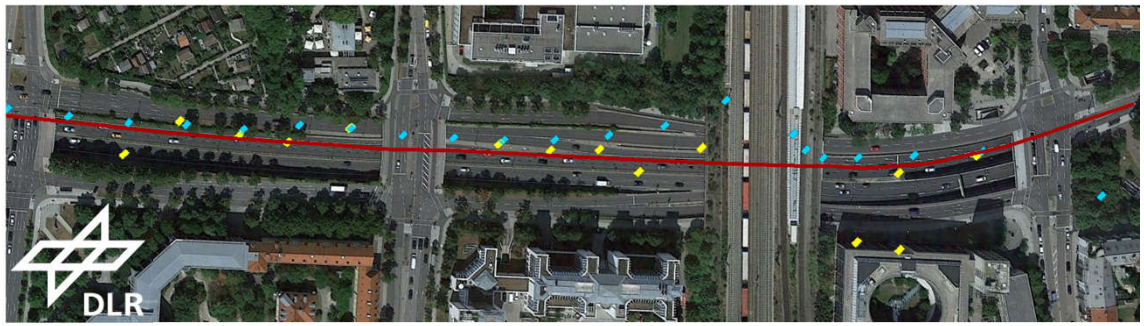
Vehicle Localization

- GNSS
  - DGPS, PPP, dual-frequency multi-constellation
- Sensor Fusion:
  - Inertial sensors
  - Perception sensors
  - Precise digital maps
- Trajectory prediction
- Accuracy vs. reliability and integrity

Urban Canyon



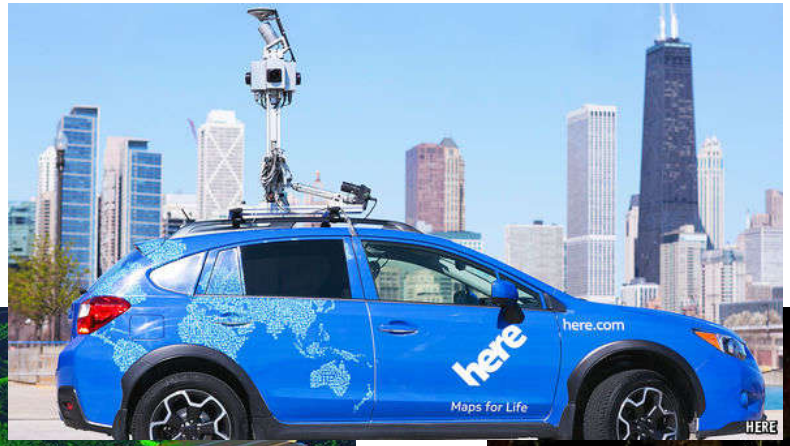
Tunnel + Bridges

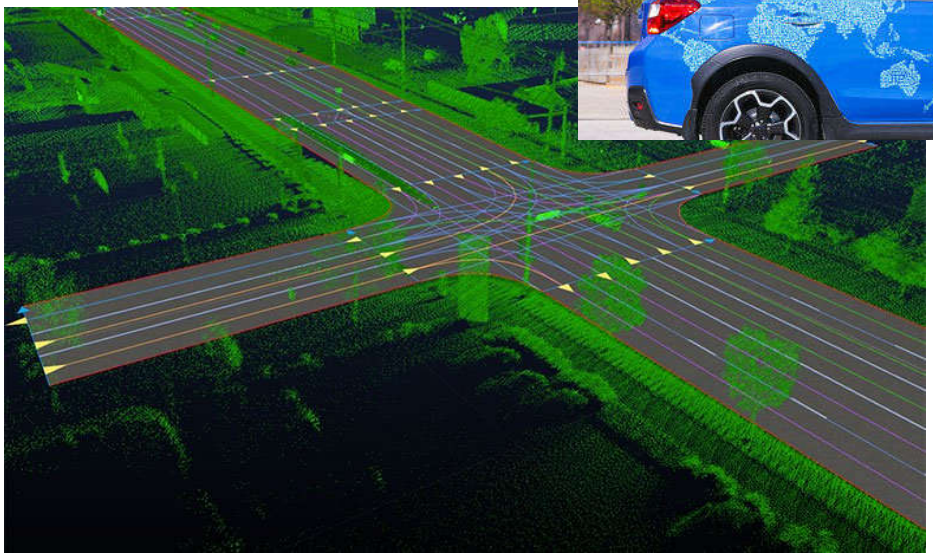


Truth Least squares KF

F. de Ponte Muller, E. M. Diaz and I. Rashdan, "Cooperative Infrastructure-Based Vehicle Positioning," *2016 IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, QC, 2016, pp. 1-6.

High Definition Maps





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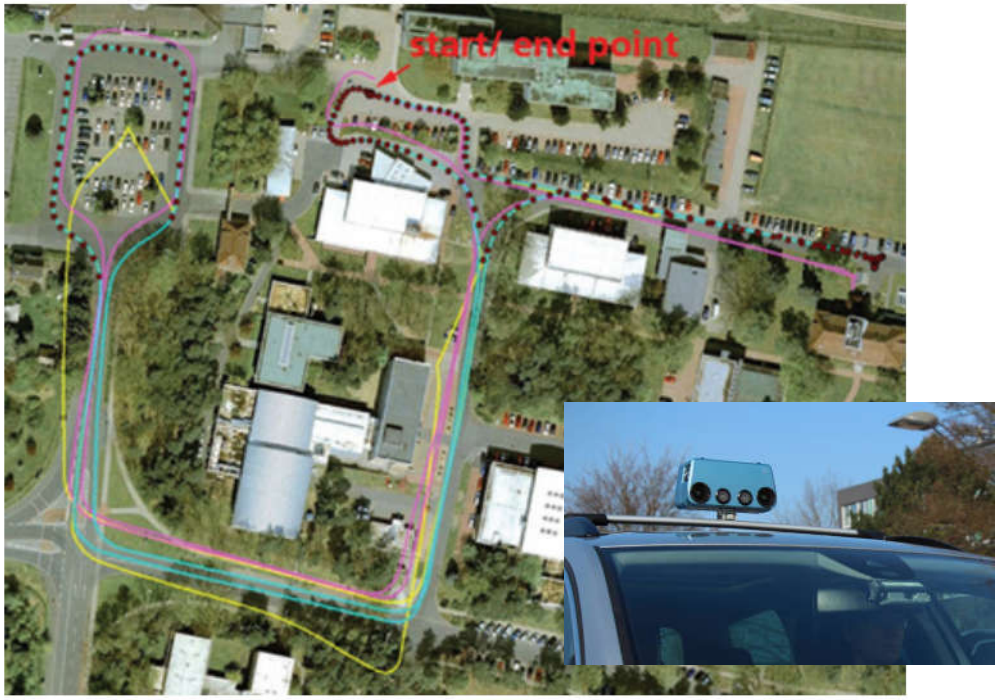
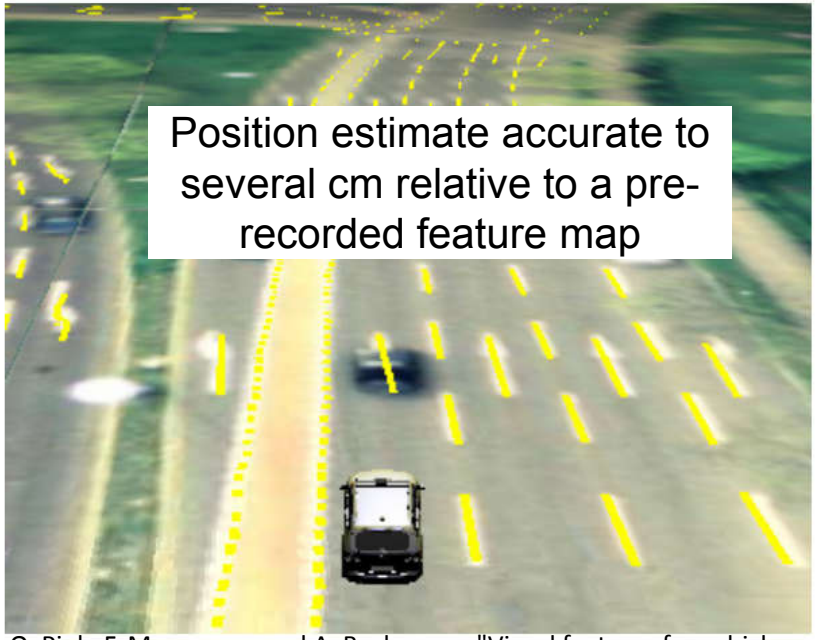
Dali.bg

Vehicle Localization – Visual Odometry



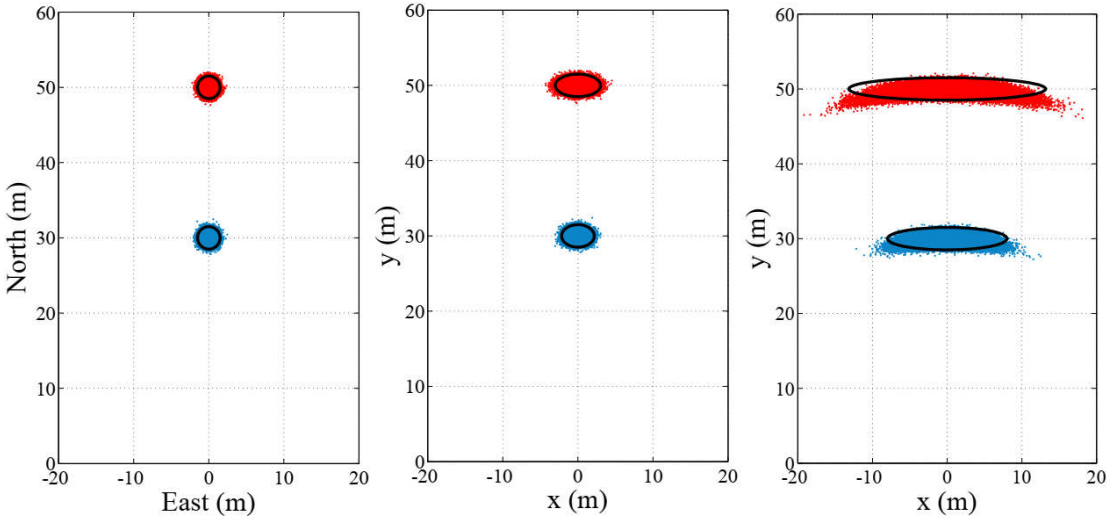
Börner, Anko und Baumbach, Dirk und Buder, Maximilian und Choinowski, Andre und Ernst, Ines und Funk, Eugen und Grießbach, Denis und Schischmanow, Adrian und Wohlfeil, Jürgen und Zuev, Sergey (2017) *IPS – a vision aided navigation system.* Advanced Optical Technologies, 6 (2), Seiten 121-130. de Gruyter



O. Pink, F. Moosmann and A. Bachmann, "Visual features for vehicle localization and ego-motion estimation," *2009 IEEE Intelligent Vehicles Symposium*, Xi'an, 2009, pp. 254-260.

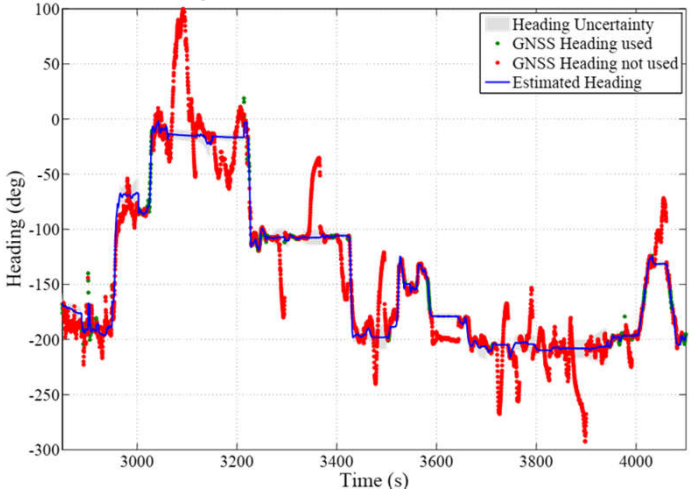
Vehicle Localization

- Vehicle heading estimation is crucial!
  - Gyroscope + Steering
  - Multiple-antenna setup
  - Magnetometer

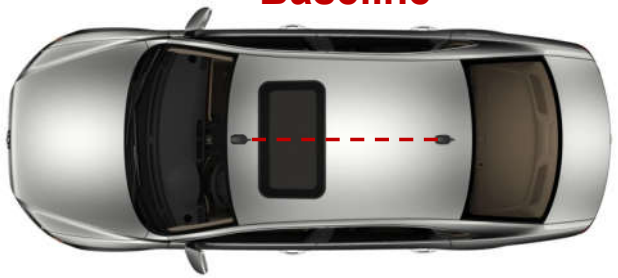


de Ponte Müller, Fabian - Survey on Ranging Sensors and Cooperative Techniques for Relative Positioning of VehiclesT2 - Sensors - 2017 - 17 - 2 - 1424-8220

Heading estimate with GNSS and IMU

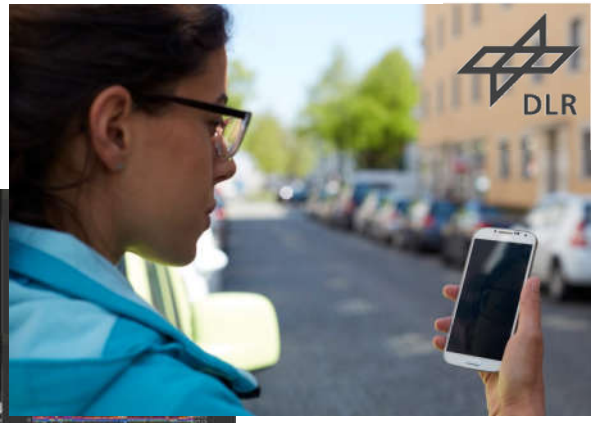


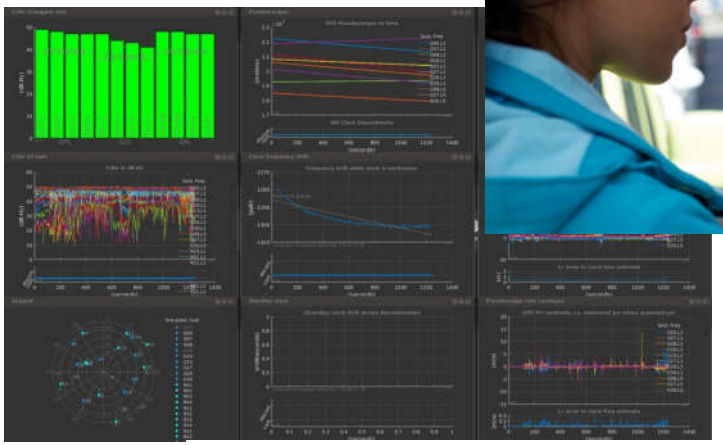
Baseline



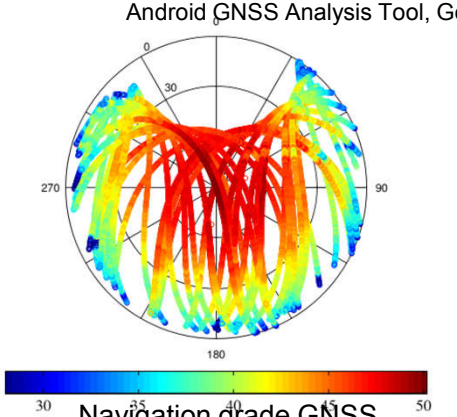
VRU Localization – GNSS in Smartphones

- Assisted GNSS
- Differential GNSS
- Broadcom BCM47755 dual-frequency GNSS receiver chip for smartphone
- Google announces supporting raw GNSS measurements from Android N on
- Challenges:
  - GNSS antenna (backplane, shielding, etc.)
  - TCXO
  - Location and orientation

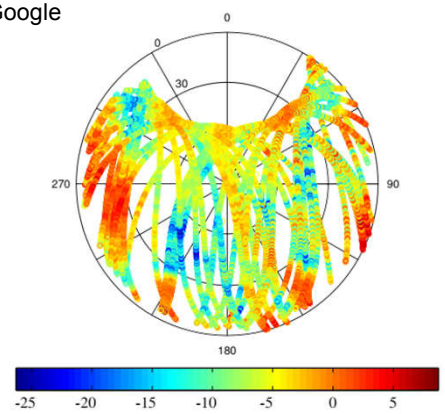




Android GNSS Analysis Tool, Google



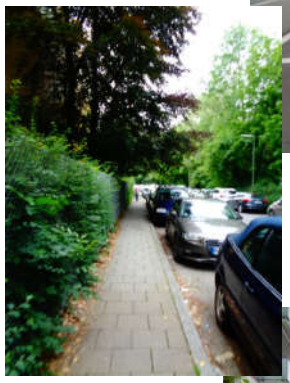
Navigation grade GNSS antenna

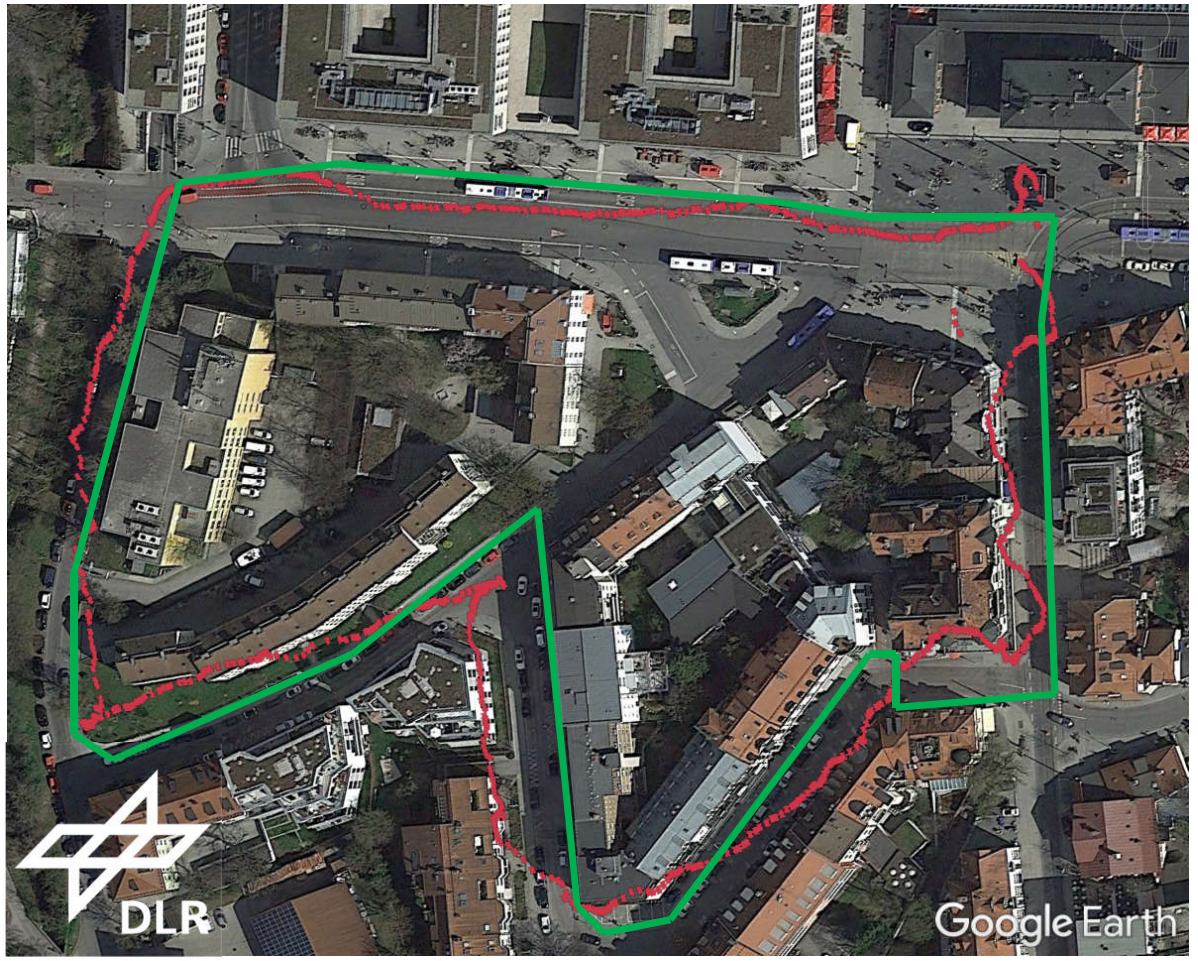


Galaxy S6 smartphone antenna

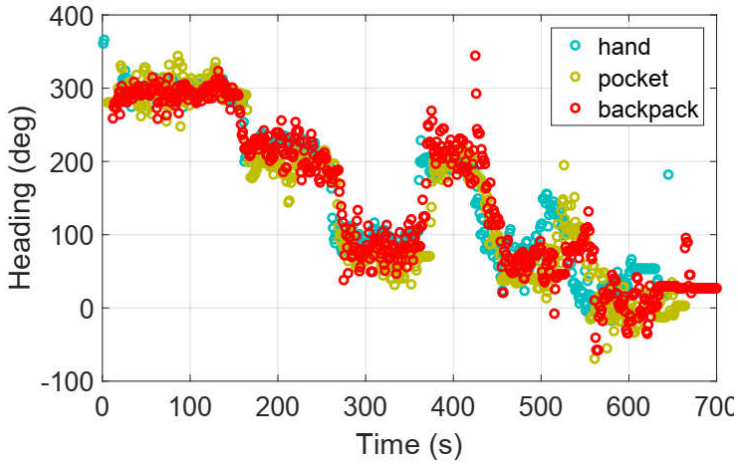
T. E. Humphreys et al. , "*On the feasibility of cm-accurate positioning via a smartphone's antenna and GNSS chip*," *2016 IEEE/ION Position, Location and Navigation Symposium (PLANS)*, Savannah, GA, 2016, pp. 232-242.

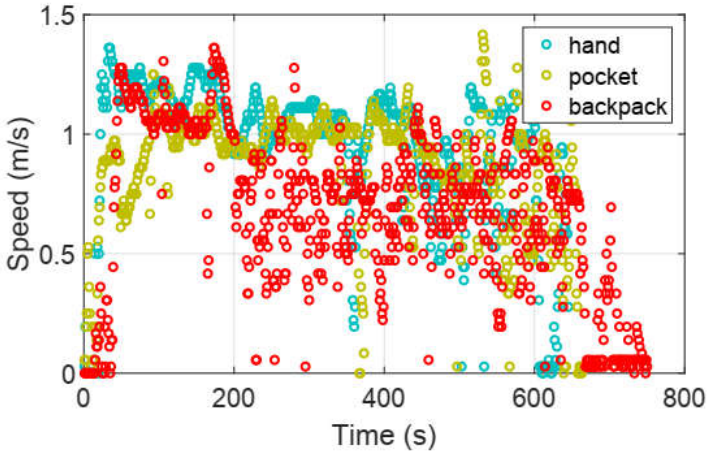
VRU Localization – GNSS in Smartphones

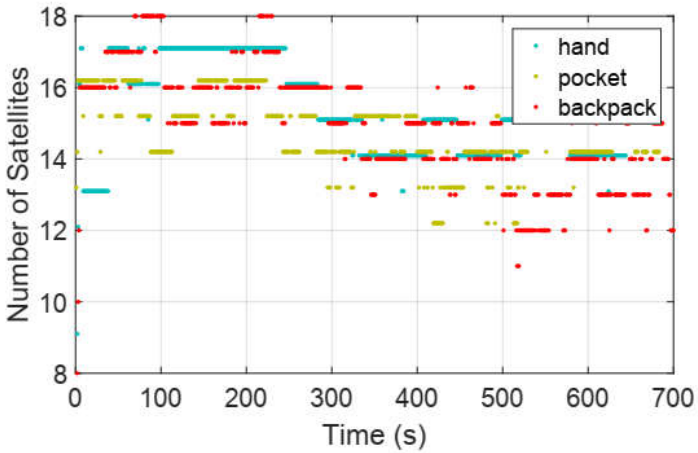




VRU Localization – GNSS in Smartphones







Urban Pedestrian Localization with GNSS and IMU

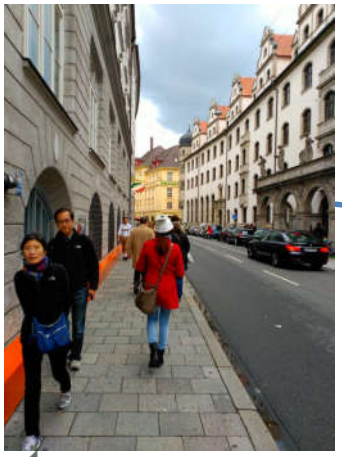
- Pedestrian Localization in the city-center of Munich
- 40 minutes
- 2.2 km length

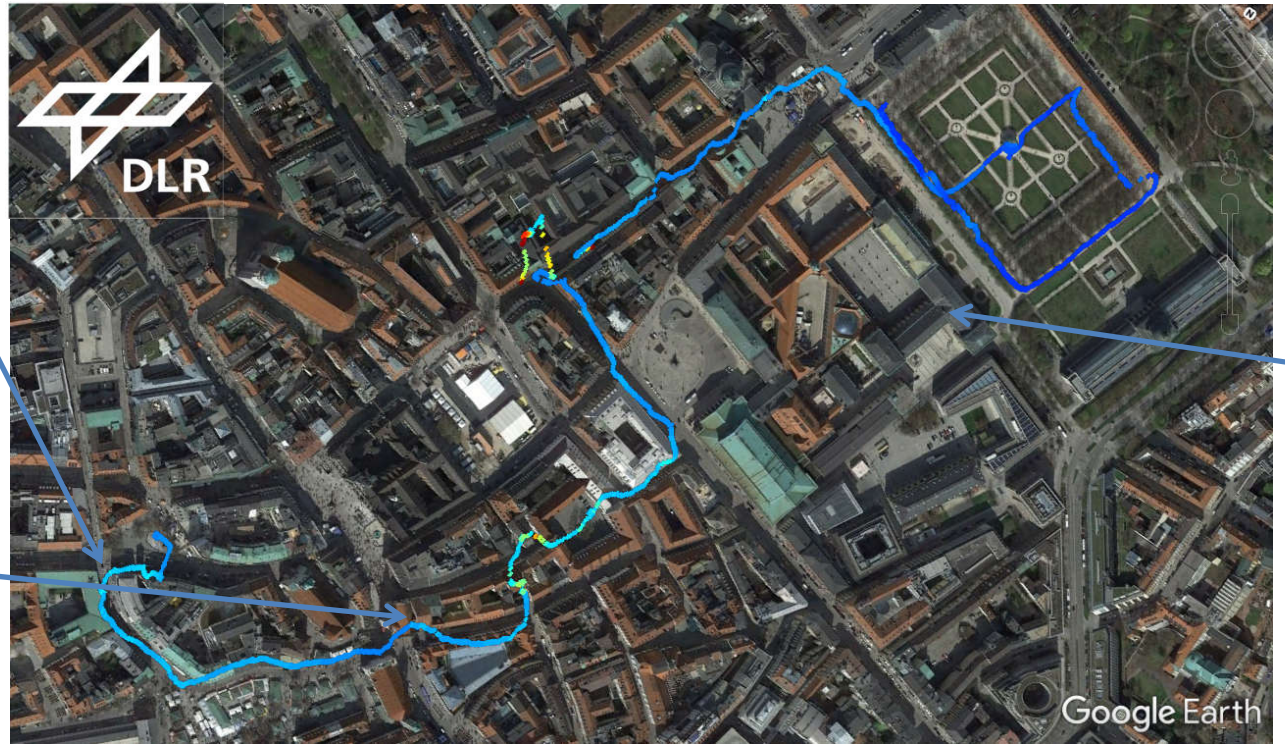
Head-mounted Patch Antenna

Ublox GPS receiver

Pocket-mounted xSens Inertial Measurement Unit

Urban Pedestrian Localization with GNSS and IMU

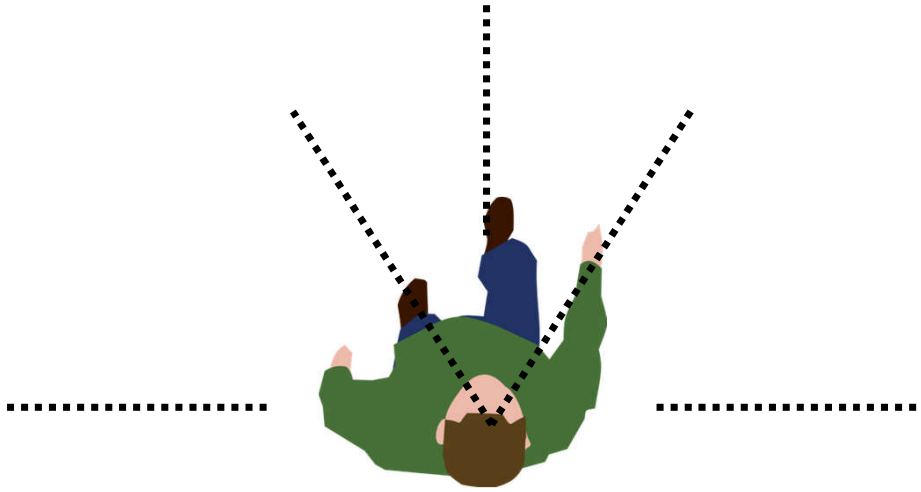


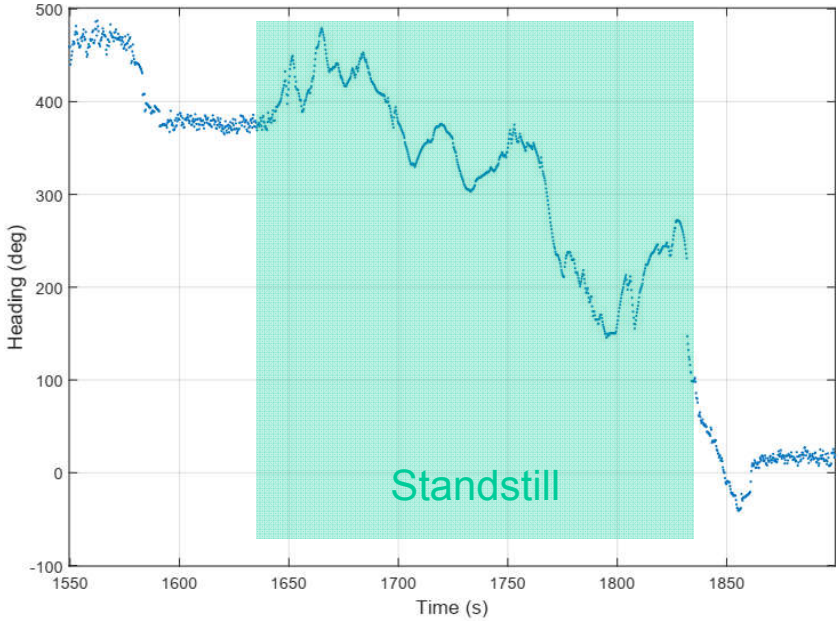


GPS Odometry True Trajectory

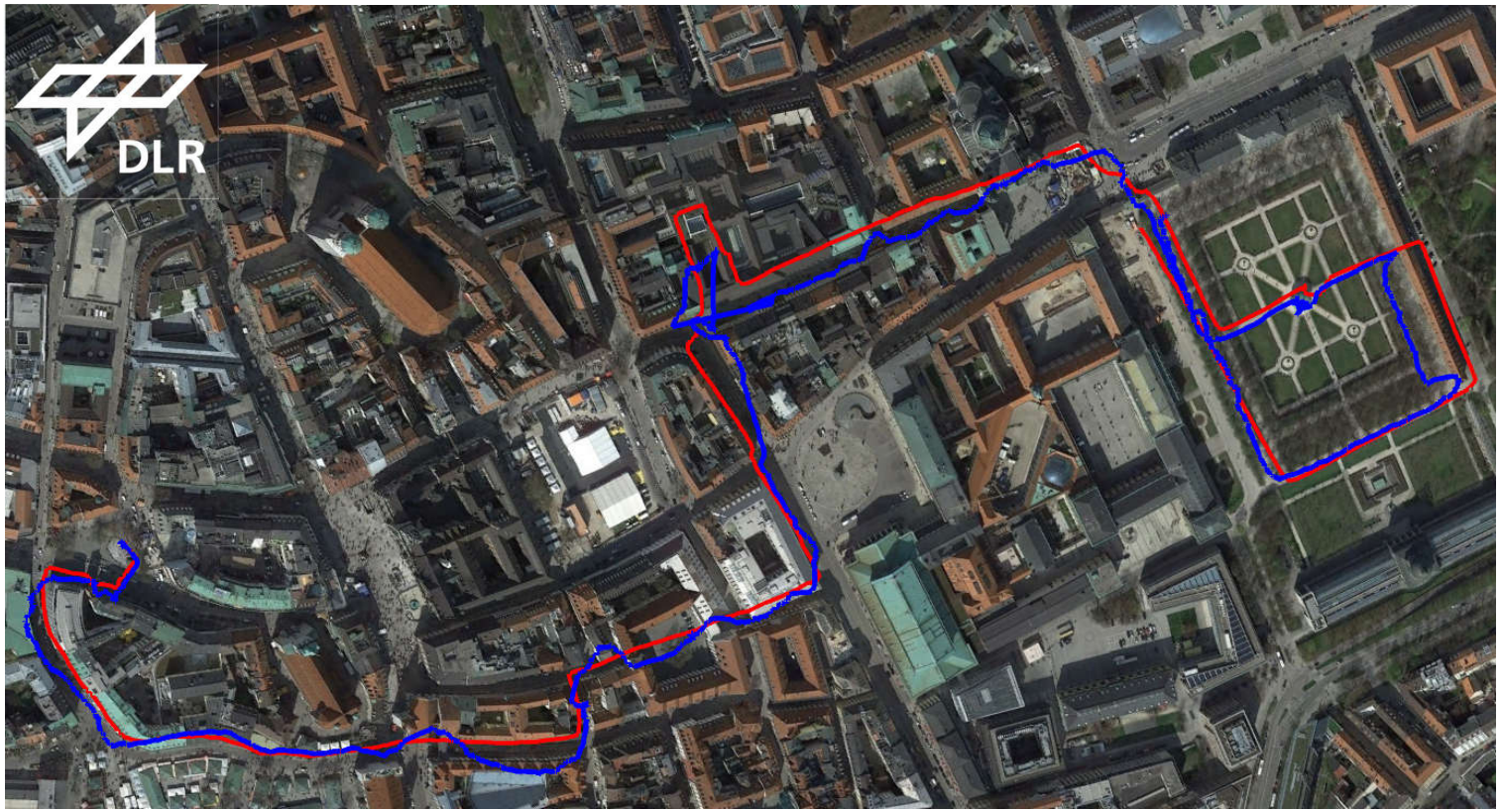
Urban Pedestrian Localization with GNSS and IMU

- Large position errors while in urban canyons
- Large position errors while standstill
- Error-prone heading while severe multipath propagation
- No reliable heading when at standstill





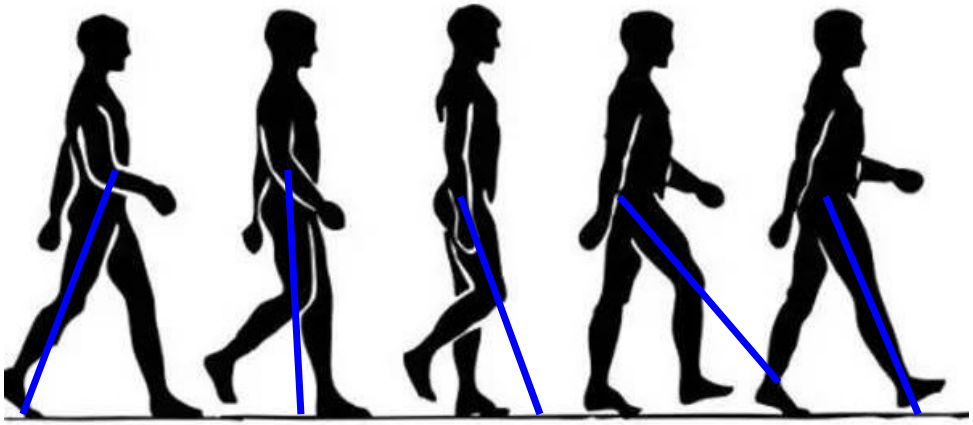
Urban Pedestrian Localization with GNSS and IMU

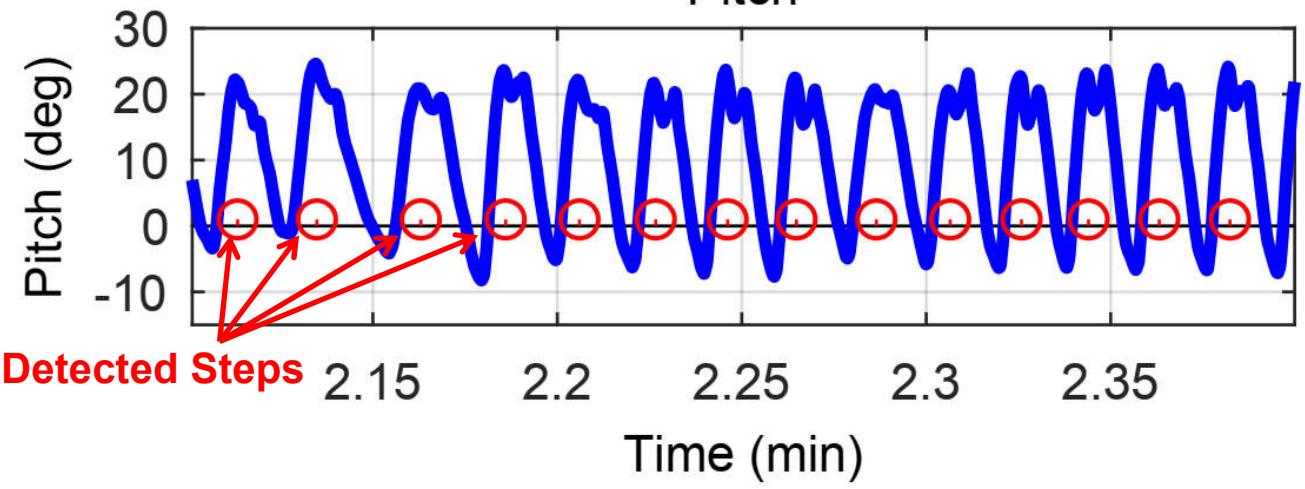


GPS Odometry Pocket-based IMU Odometry with compensated Drift

Urban Pedestrian Localization with GNSS and IMU

- Wearable device in the pedestrian's pocket
  - Heading angle → Direction of movement
  - Pitch angle → Opening angel of the leg





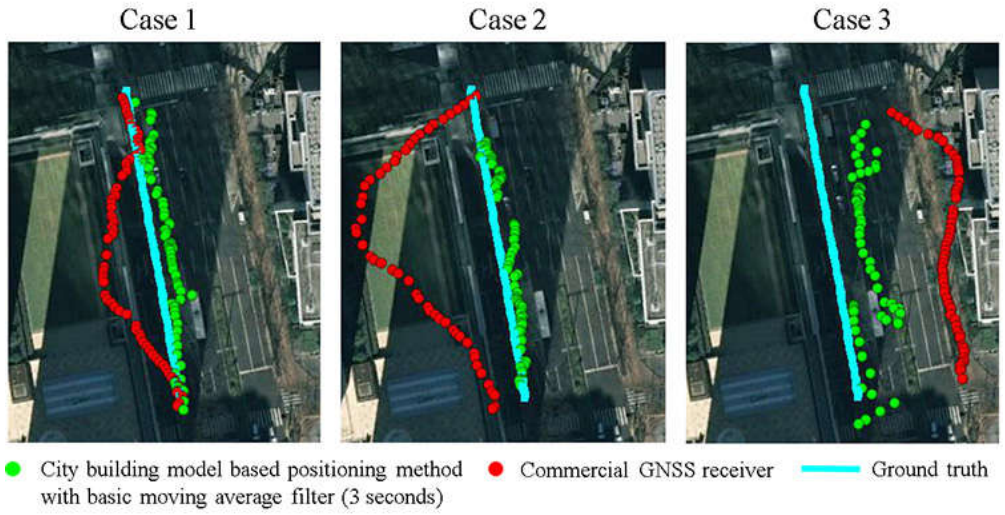
VRU Localization

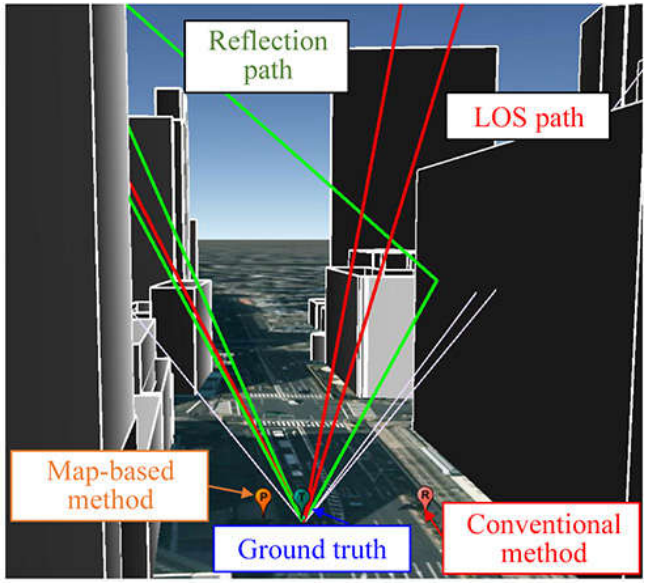
- Context information
  - Navigation: Where is the road user heading?
  - Activity recognition:
    - Means of transport: cycling, kick-scooter, skates, etc.
    - Walking, standing, gazing, …
    - Texting, phoning,…
  - Age, physiological/psychological indicators
  - Turning lights in vehicle, wipers, …
  - Traffic light phase

BMW

Enhanced GNSS Localization in urban Environments

- Filtering GNSS observables: elevation mask, CN0, polarization, etc.
- Usage of 3D maps



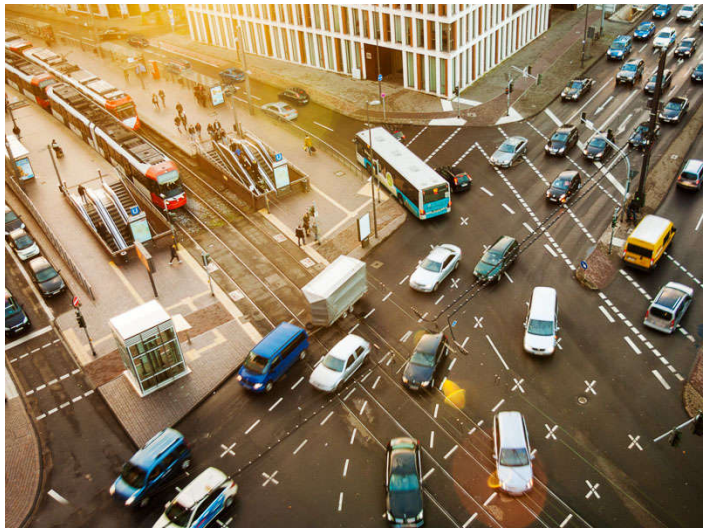


Source: Li-Ta Hsu, Shunsuke Miura and Shunsuke Kamijo *Street Smart: 3D City Mapping and Modeling for Positioning with Multi-GNSS*, 2015 Inside GNSS

VRU Localization - Maps

- Reliable path prediction via static and dynamic maps.
- Path prediction

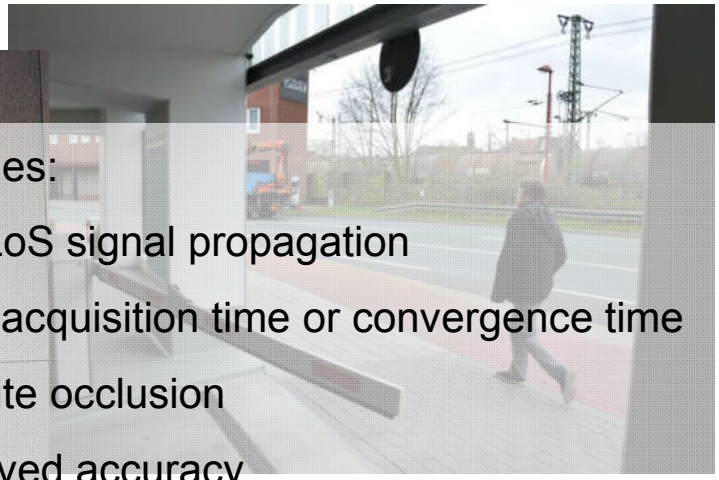
Source: W. C. Ma, D. A. Huang, N. Lee and K. M. Kitani, "Forecasting Interactive Dynamics of Pedestrians with Fictitious Play," *2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, Honolulu, HI, 2017, pp. 4636-4644.



Christian Hinkelmann

Challenges Road User Localization

Ralph Ribi



https://haz.de/

Challenges:

- Non-LoS signal propagation
- Short acquisition time or convergence time
- Satellite occlusion
- Improved accuracy
- Measure of reliability and integrity

https://www.contipark.de

https://www.weser-kurier.de

www.eschenhof-pasing.de

VRU Localization through Radio Ranging

- Opportunities with 5G
  - Larger bandwidth → Higher time resolution → Better ranging accuracy
  - mmWave: AoA, dense networks
  - Studies on network-based positioning foresee position accuracies at dm-level:

"Assisted driving with accuracies below 30 cm is possible with high signal bandwidths, i.e., 50 and 100 MHz."

J. A. del Peral-Rosado, J. A. López-Salcedo, Sunwoo Kim and G. Seco-Granados, "Feasibility study of 5G-based localization for assisted driving," *2016 International Conference on Localization and GNSS (ICL-GNSS)*, Barcelona, 2016, pp. 1-6.

- IEEE 802.11 for Ranging for indoors and outdoors: Next Generation Positioning Working Group in IEEE
- Ultrawideband ranging

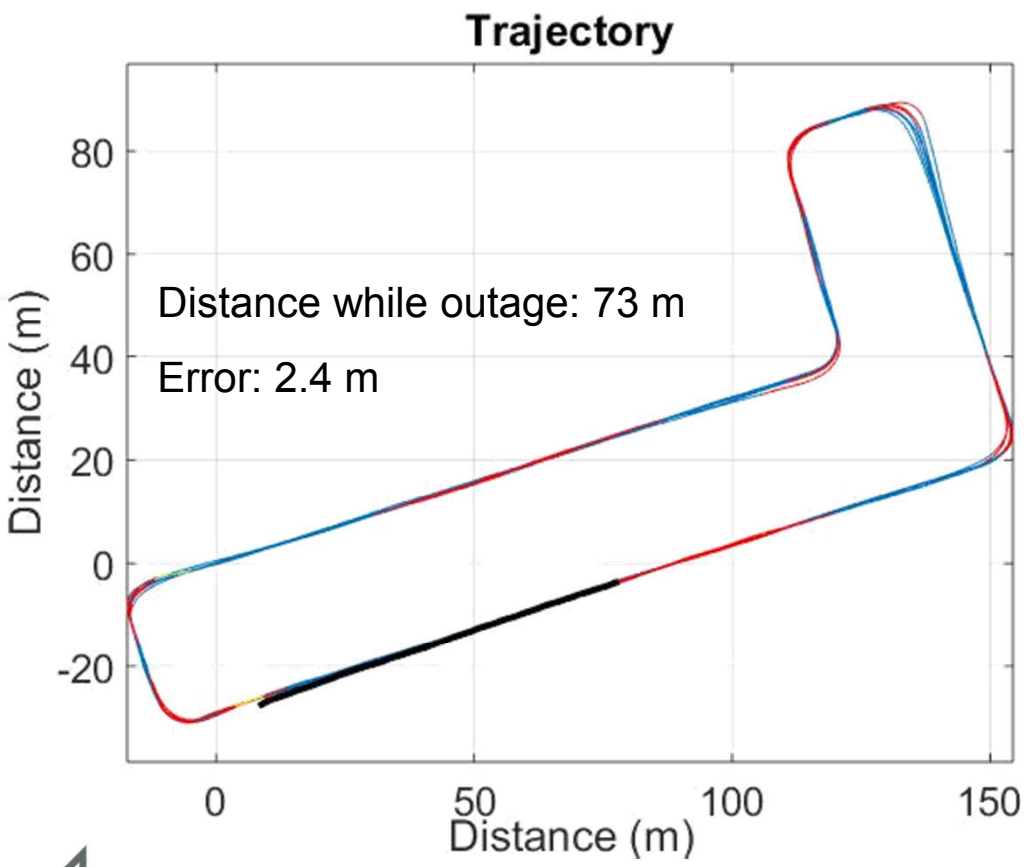
Inertial-aided Bicycle Localization

- IMU placed on:
  - Glasses
  - Wrist
  - Pocket
  - Foot
- RTK system:
  - Ground truth position
  - Ground truth speed

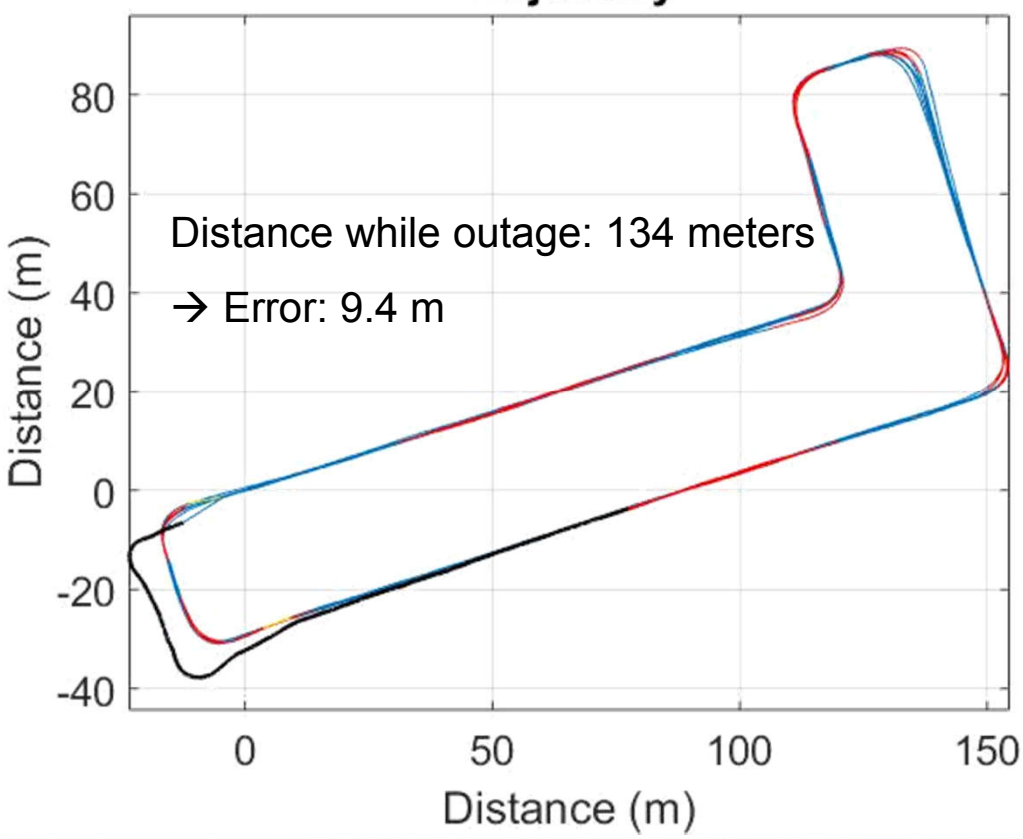
Source: Munoz Diaz, Estefania, de Ponte Müller und Eduardo Perez Gonzalez (2018) *Intelligent Urban Mobility: Seamless Navigation of Pedestrians and Bicycles*. In: 2018 International Conference on Indoor Positioning and Indoor Navigation (IPIN). 9th International Conference on Indoor Positioning and Indoor Navigation, Nantes, France.

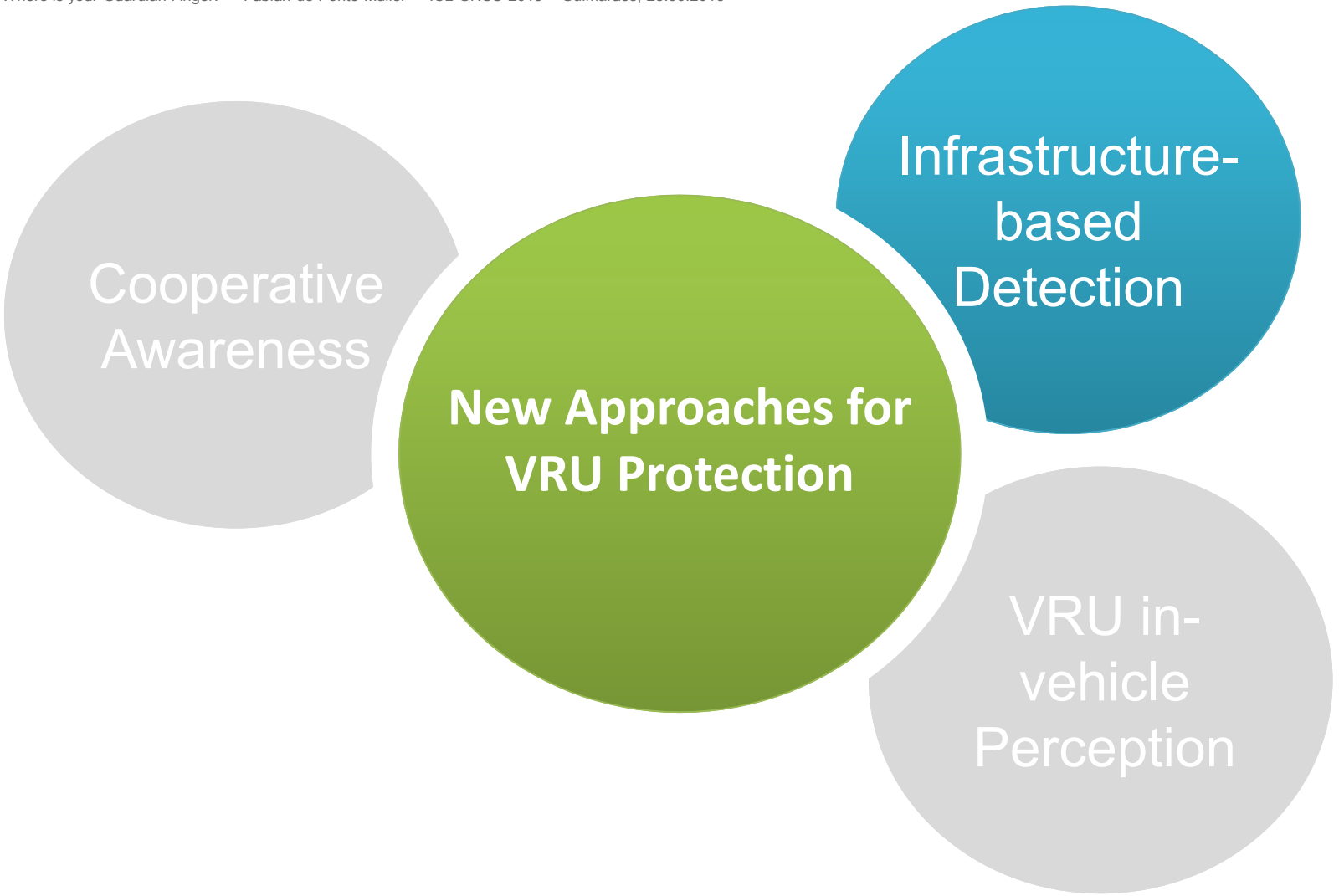
Inertial-aided Bicycle Localization

20 second GNSS Outage



40 second GNSS Outage



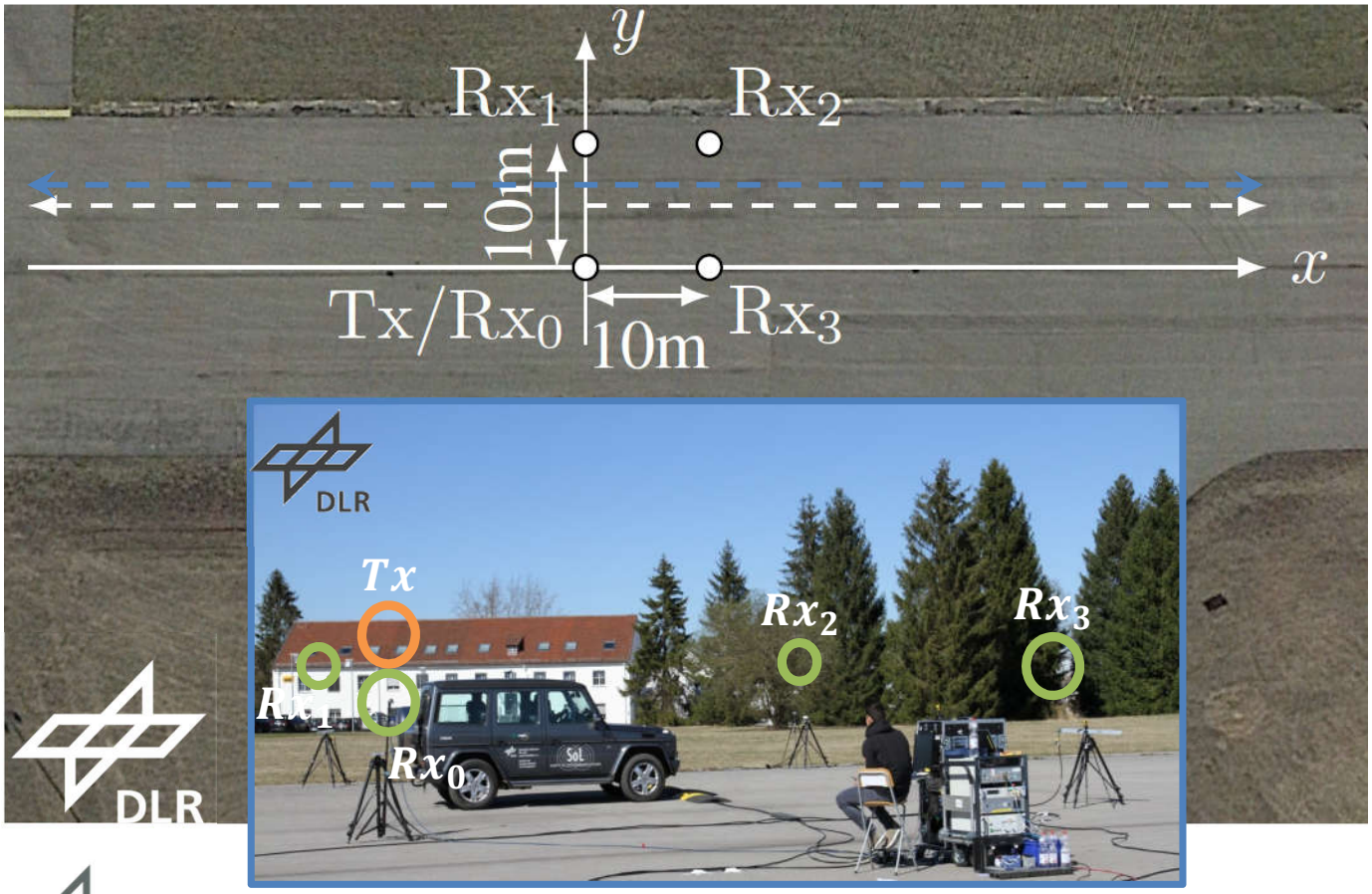

Cooperative Awareness
Infrastructure-based Detection
New Approaches for VRU Protection
VRU in-vehicle Perception

Infrastructure-based Localization

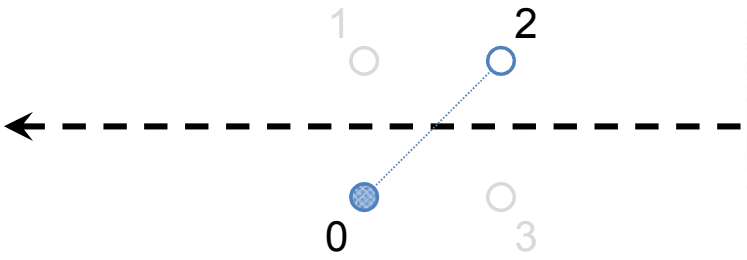
- Electronic Fence: re-use existing V2I communication infrastructure (e.g. integrated in lamp poles) to:
  - Detect
  - Classify
  - Localize

  } All types of road users

Measurement Campaign – Overview

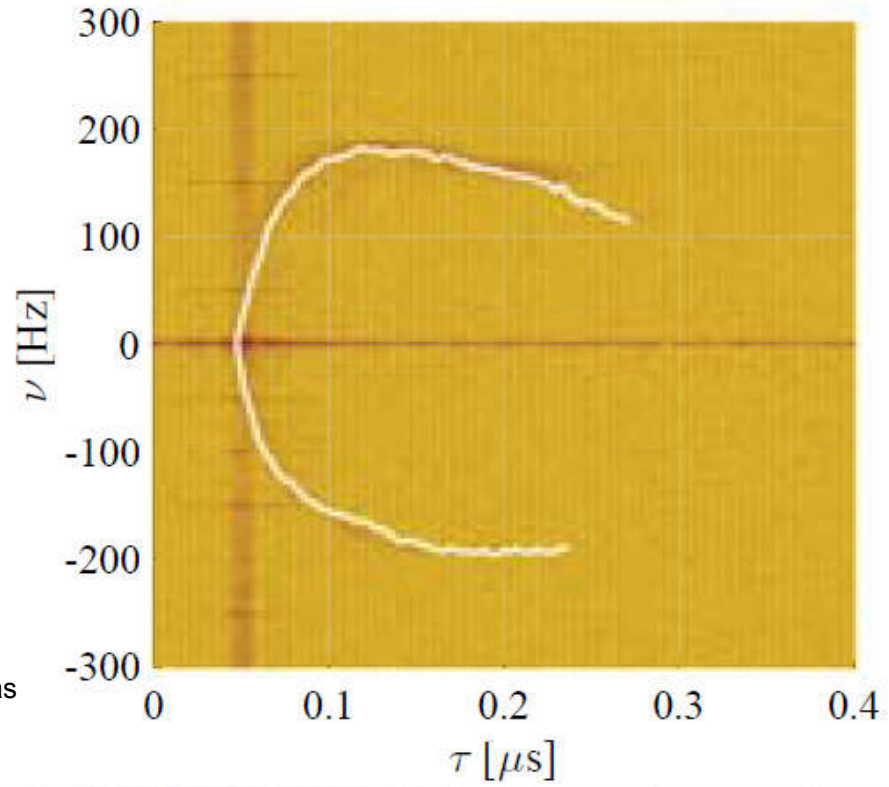


Delay-Doppler Profile



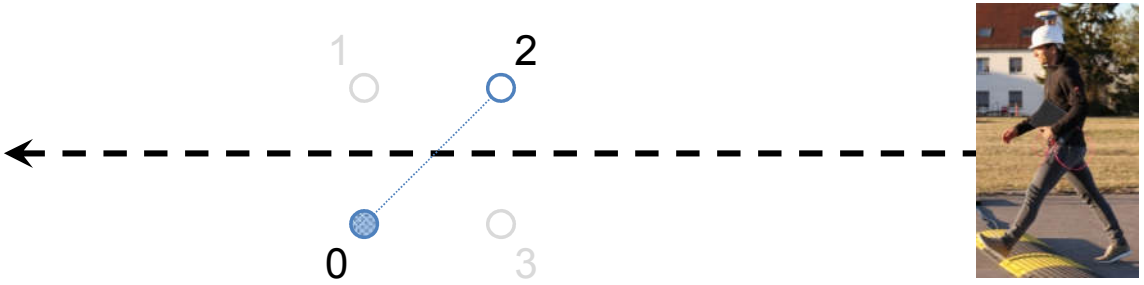
Mercedes G 400

- Transceiver pair $Tx\text{-}Rx_2$
- Movement in one direction
  - track distance $100m$
  - $Tx\text{-}Rx$ baseline crossed
- CIR samples over full movement period for calculation of delay-Doppler profile



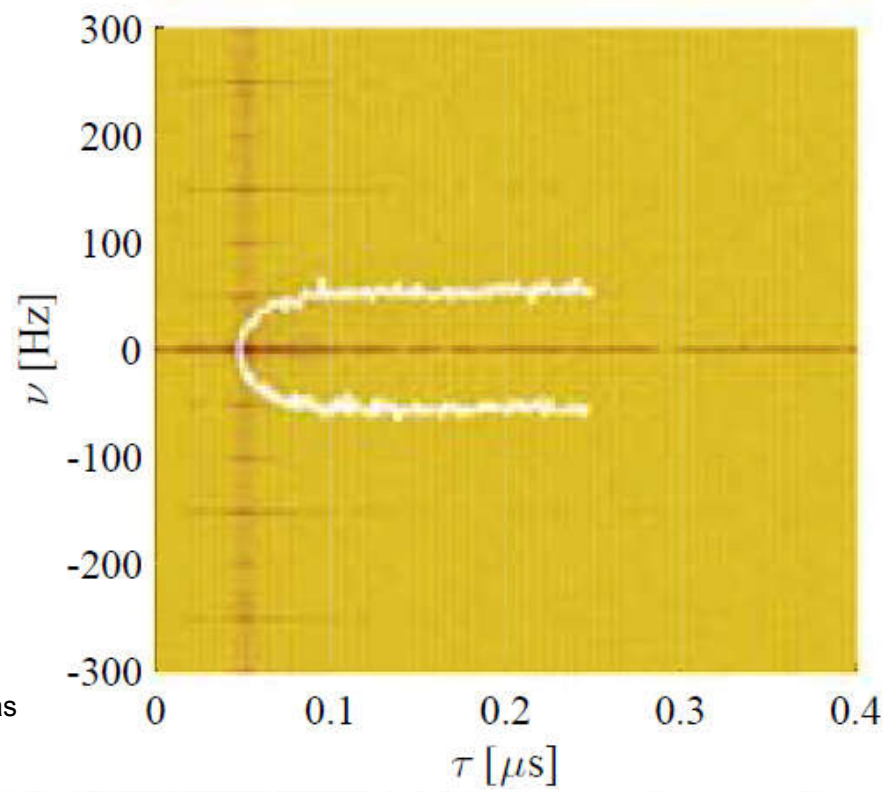
Source: Schmidhammer, Martin und De Ponte Müller, Fabian und Sand, Stephan und Rashdan, Ibrahim (2018) *Detection and Localization of Non-Cooperative Road Users based on Propagation Measurements at C-Band*. 12th European Conference on Antennas and Propagation (EuCAP), London, Great Britain.

Delay-Doppler Profile



Pedestrian

- Transceiver pair $Tx\text{-}Rx_2$
- Movement in one direction
  - track distance $100m$
  - $Tx\text{-}Rx$ baseline crossed
- CIR samples over full movement period for calculation of delay-Doppler profile



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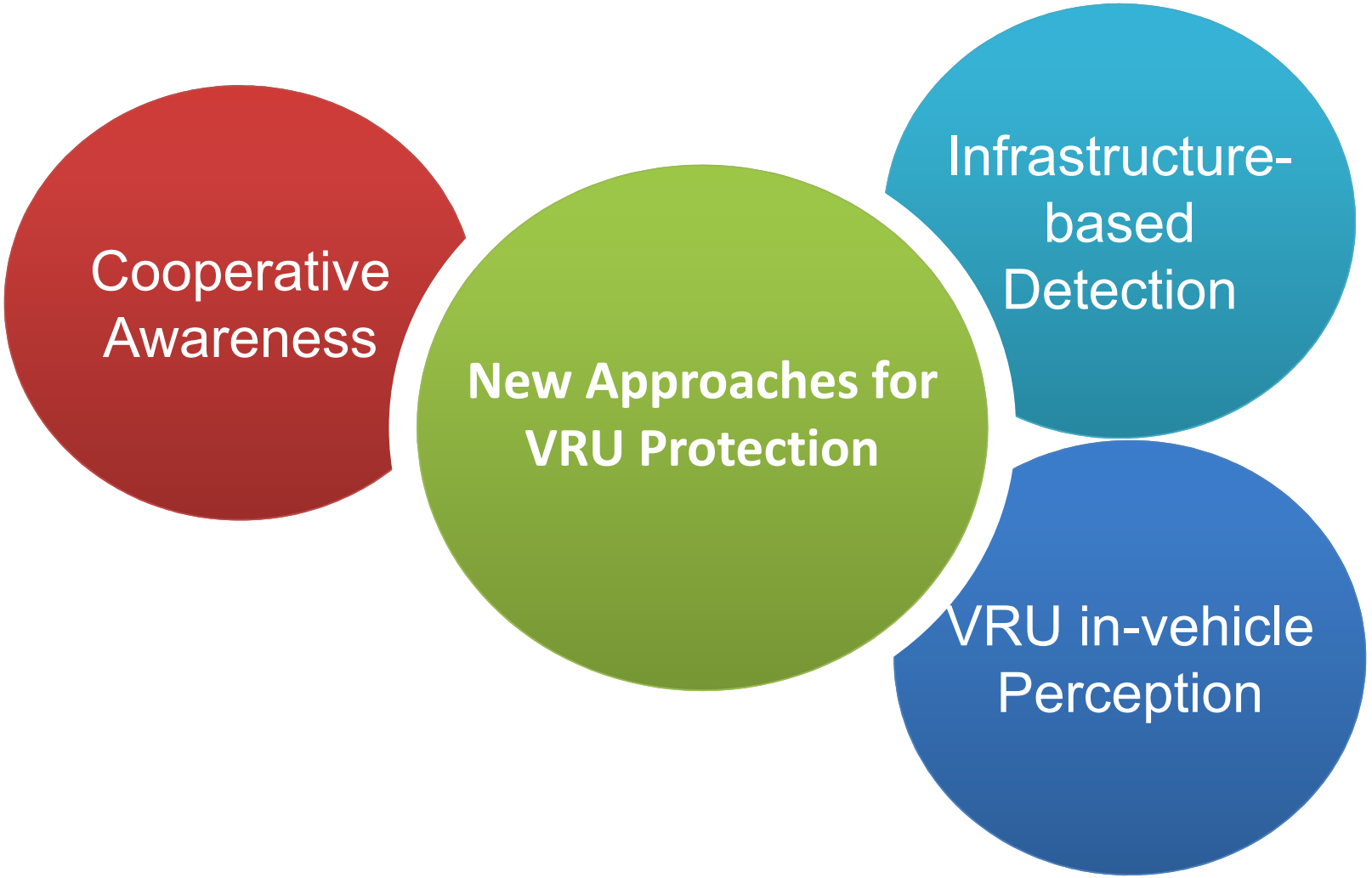
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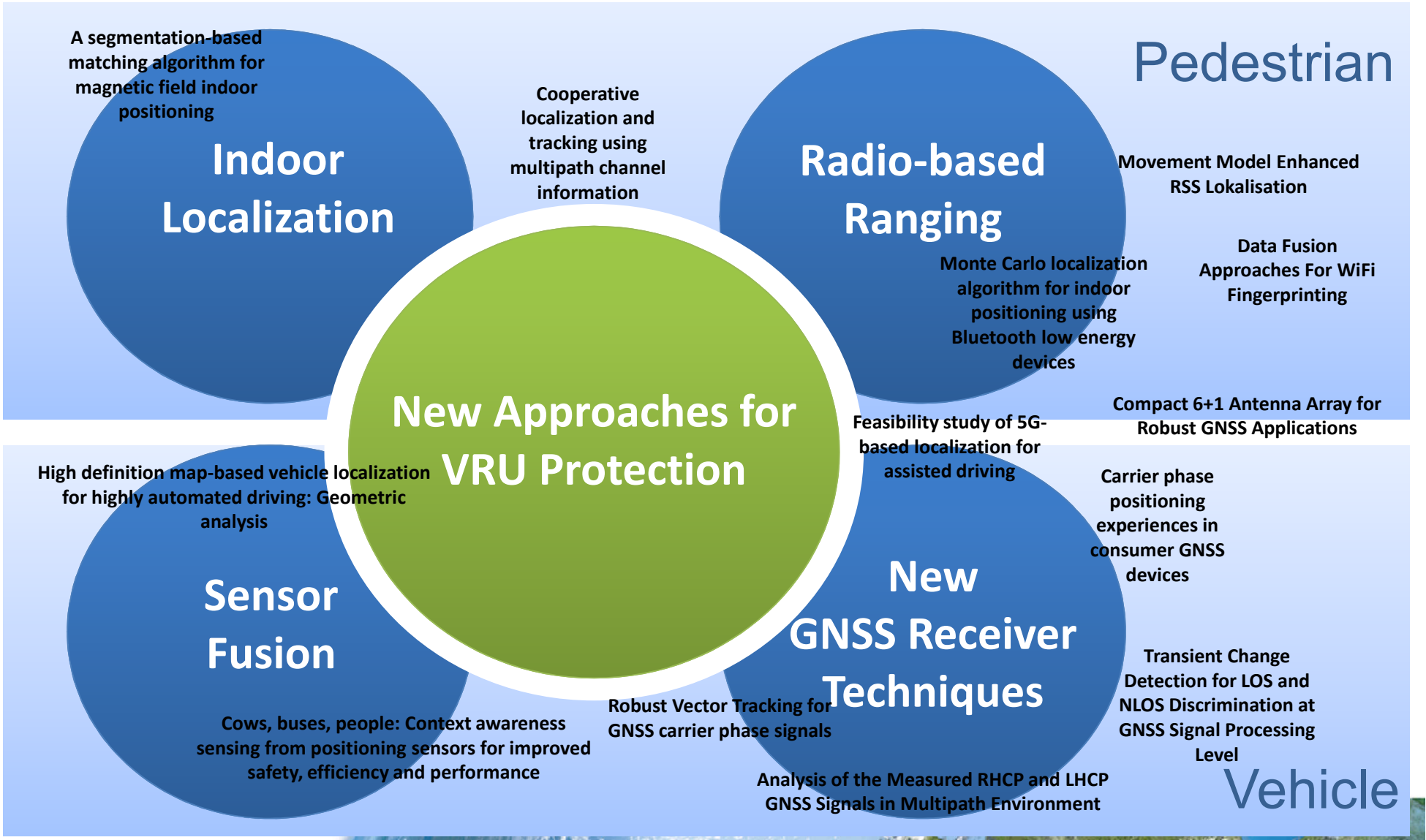
ICL-GNSS 2016 & 2017



DLR

ICL-GNSS - 2018

DLR

So…Where is your Guardian Angel?

- In-vehicle VRU perception
- Reliable and accurate ego-localization and ego-kinematics
- Robust V2X communication
- Additional infrastructure-side localization

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